LEVEL II

AD A097736

AFWAL-TR-80-3098

VALIDATION OF A BIRD SUBSTITUTE FOR DEVELOPMENT AND QUALIFICATION OF AIRCRAFT TRANSPARENCIES.

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UDR-TR-80-69

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Technical Report AFWAL-TR-80-3098
Final Report. [redacted] Jul [redacted] 79 — Jul [redacted] 80,

F33615-78-C-3402

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FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFWAL-TR-80-3098
2. GOVT ACCESSION NO.: AD-A097736
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): VALIDATION OF A BIRD SUBSTITUTE FOR DEVELOPMENT AND QUALIFICATION OF AIRCRAFT TRANSPARENCIES
5. TYPE OF REPORT & PERIOD COVERED: FINAL TECHNICAL REPORT JULY 1979 - JULY 1980
6. PERFORMING ORG. REPORT NUMBER: UDR-TR-80-69
7. AUTHOR(s): ANTONIOS CHALLITA
8. CONTRACT OR GRANT NUMBER(s): F33615-78-C-3402
9. PERFORMING ORGANIZATION NAME AND ADDRESS: UNIVERSITY OF DAYTON RESEARCH INSTITUTE 300 COLLEGE PARK AVE. DAYTON, OHIO 45469
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PROG. ELE. 62201F PROJ. 2402, TASK 240203 WORK UNIT 24020318
11. CONTROLLING OFFICE NAME AND ADDRESS: FLIGHT DYNAMICS LABORATORY (FI) AF WRIGHT AERONAUTICAL LABORATORIES, AFSC WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
12. REPORT DATE: OCTOBER 1980
13. NUMBER OF PAGES: 76
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Foreign object damage, bird substitute, transparencies, bird impact, minimum perforation velocity, polycarbonate panels, impact loads.
20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This report describes an experimental study designed to validate a substitute bird for development and qualification of aircraft transparencies. For a substitute bird to be accepted by the transparency community it has to generate the same impact loads as real birds and damage the transparency in the same manner. Nominal 450 g real and spherical substitute birds were launched onto 0.635 cm thick polycarbonate panels at four

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different locations. The minimum perforation velocity was used as the main criterion to measure damage; however, perforation wasn't achieved at the center panel and at the lower, or upstream, corner. Therefore, other measures of damage were adopted for these locations; length of cracks, depth of pocket, etc. Also, temporal and spatial distribution of loads were measured for 60 and 600 g spherical substitute birds at three impact angles (90°, 45°, and 25°) and three velocities (100, 200, 300 m/s). Time-pressure traces recorded in this program showed a rise and decay of a shock pressure; no steady-state flow was observed. A direct comparison of the damage potential of real birds, spherical substitute birds, and end-on cylinders (measured in a previous program where effects of orientation at impact were studied) shows that end-on cylinders have similar damage potential to real birds, and from previous work reported by Challita et al in Reference 3 we know that end-on cylinders generate similar impact loads to real birds; therefore, end-on cylinders were selected as the substitute birds to be used in development and qualification of transparencies.

FOREWORD

This report describes a contractual work effort conducted by personnel of the Impact Physics Group within the Experimental and Applied Mechanics Division at the University of Dayton Research Institute for the Flight Dynamics Laboratory under Project 2402, "Vehicle Equipment Technology," Task 240203, "Aerospace Vehicle Recovery and Escape Subsystems," Work Unit 24020318, "Simulation of Bird Impact on Aircraft Transparencies." The Project Monitor was Mr. Robert E. McCarty and Mr. George Roth was the Project Supervisor for the University. Dr. John Barber and Mr. Blaine West contributed to planning the experiments.

This report is the last of three to be published under Contract No. F33615-78-C-3402. The first two dealt with scaling the impact loads and studying the effects of bird orientation at impact on damage level.

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LIST OF ILLUSTRATIONS

LIST OF UNITS

Mass	g (gram)	=	0.0022 lb_m (pounds-mass)
	kg (kilogram)	=	10^3 g
Length	m (meter)	=	3.2808 ft (feet)
		=	39.37 in (inches)
	cm (centimeter)	=	0.01 m
		=	0.3937 in
	mm (millimeter)	=	0.001 m
Time	s (second)		
	μs (microsecond)	=	10^{-6} s
Force	N (Newton)	=	0.2248 lb_f (pounds-force)
	MN (Meganewton)	=	10^6 N
Density	kg/m^3	=	0.0624 lb_m/ft^3
		=	3.613×10^{-5} lb_m/in^3
Pressure	MN/m^2	=	10 bars
		=	145.04 lb_f/in^2
Frequency	H_z (hertz)		
	kH_z (kilohertz)	=	10^3 H_z

LIST OF SYMBOLS

D	Diameter of the bird
ID	Inside diameter
L	Length of the bird
OD	Outside diameter
P, P_p	Measured peak pressure
P_H	Hugoniot pressure
t	Time
V	Impact velocity
V_n	Normal component of impact velocity
V_s	Shock velocity
ρ	Density of projectile
θ	Angle of impact

SECTION I
INTRODUCTION

Birds and aircraft occupy the same air space and collisions between the two are inevitable. As a result of the increasing number of catastrophic bird-aircraft collisions, the United States Air Force has initiated a number of programs with the objective of developing and applying the technology required to protect aircraft against birdstrike. Some of these programs have dealt with characterization of the loads generated during a birdstrike and with the testing procedure used to evaluate the level of birdstrike protection afforded by a given flight hardware system.

A strong random variation was found in the bird impact loads data collected during the early stages of the bird impact studies. These variations were apparently due to inherent variability in material properties, structures, and geometry of birds. This fact raised serious questions about the conduct of test programs using real birds to screen candidate transparency designs. It was therefore desirable to develop and validate a suitable substitute bird which has much more repeatable impact loads and will contribute significantly to the clear interpretation of such test results. This report deals with the validation of such a substitute bird.

1. BACKGROUND

Early investigations of bird impact loading conducted at the Air Force Materials Laboratory and the University of Dayton Research Institute identified a number of deficiencies in the use of real birds as a testing medium. These were attributed to the inhomogeneity of real birds and the irregular geometry of the bird carcass. Thus, the use of real birds in development and qualification testing introduces unknown and uncontrollable experimental variables. In addition, it is often desirable to perform subscale laboratory tests

during development of transparency components rather than full-scale component tests. Since birds are not available in a variety of well defined and controlled sizes, subscale laboratory testing with real birds is often impossible. An easily fabricated and scaleable substitute bird is essential for laboratory subscale testing. It was, therefore, desirable to develop and validate a suitable substitute bird for use in transparency impact testing.

For a substitute bird to be accepted for development and qualification testing of transparencies, it is necessary to demonstrate that the substitute bird generates substantially the same loads as a real bird during impact; and that it does the same damage to a transparency as a real bird. If the substitute bird has the same material properties and geometry as a real bird, it will generate the same impact loads. The theoretical work reported by Wilbeck in Reference 1 demonstrated that a good material substitute for birds is gelatin with 10 to 15 percent porosity. This material was molded as right circular cylinders and was extensively tested in the first and second phase of this contractual effort, and was found to generate the same impact loads as real birds when launched with end-on orientation. This work was reported by Challita in References 2 and 3.

The geometry and orientation at impact of the bird are two important factors which should be considered while developing and validating a substitute bird. The pressure data collected at AEDC and reported by Barber in Reference 4 showed

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1. Wilbeck, J.S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.
2. Challita, A. and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.
3. Challita, A. and J.P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.
4. Barber, J.P., J.S. Wilbeck, and H.R. Taylor, "Bird Impact Forces and Pressures on Rigid and Compliant Targets," AFFDL-TR-77-60, May 1978.

pronounced effects of orientation on bird impact pressures. Therefore, a test program was conducted where cylindrical gelatin birds were launched with controlled orientation and the effects of orientation at impact were studied and the worst-case orientation was identified and recommended to be used in subsequent design and proof testing of aircraft transparencies. This work was reported by Challita in Reference 2.

The geometry of a real bird is approximately an oblate spheroid. Most substitute birds currently used are right circular cylinders, and for many testing circumstances it would be advantageous to remove orientation as a test variable. Therefore, it was proposed that a direct comparison of the damage caused by a spherical substitute bird and the damage caused by a real bird be conducted.

2. PROGRAM OBJECTIVES

The experimental program described in this report was designed to validate a substitute bird and recommend it for development and qualification of aircraft transparencies. To achieve this objective, 450 g spherical substitute birds and real birds were launched at a 90 x 60 x 0.635 cm flat polycarbonate panel at a 25 degree angle of incidence, and at four impact locations; center, edge, and two corners. Then, the data collected from this task and from task II, where the effects of orientation at impact were studied, were used in an analysis to quantitatively compare the target damage inflicted by cylindrical substitute birds, spherical substitute birds, and real birds. In addition, 60 and 600 g spherical substitute birds were launched onto rigid flat plates, where temporal and spatial distribution of loads were measured, at three impact

2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

angles (90, 45, and 25 degrees) and at three velocities (100, 200, 300 m/s). This was accomplished in order to investigate the scaleability of the substitute bird material.

SECTION II
EXPERIMENTAL TECHNIQUES

The experimental work described in this report was conducted at the University of Dayton Research Institute. This section contains a description of the experimental techniques used to launch 450 g spherical bird substitutes (gelatin with 10 percent porosity) and real birds (pigeons) onto nominal 0.635 cm flat polycarbonate panels at an impact angle of 25 degrees. Techniques used to obtain temporally resolved pressure measurements during spherical bird substitute impact onto a rigid steel target plate are also described. Descriptions of the experimental ranges, launch techniques, target structure, instrumentation, and data collection are given in the sections that follow.

1. LAUNCH TECHNIQUES

Soft body launchers must be capable of accelerating packages (projectile and sabot) of a required mass to a required velocity without inducing any projectile breakup or severe distortion prior to impact. Also, projectiles must be launched with controlled orientation (preferably with zero pitch and yaw). Therefore, launch techniques were developed with which projectiles of up to 3.6 kg could be launched at velocities up to approximately 300 m/s.

Two systems were used: a 177.8 mm bore and an 88.9 mm bore compressed gas gun. The large bore gun was used to launch projectiles with diameter greater than 76.2 mm. A description of both systems follows.

a. The 177.8 mm Bore Launcher

A detailed description of this system was reported by the author in References 2 and 3, and can be summarized as being

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2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

3. Challita, A., and J.P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.

composed of a 177.8 mm bore compressed gas gun with supporting compressor, instrumentation, and control systems. An overall view of the 177.8 mm gun range is shown in Figure 1. The gun range consists of:

(1) A storage tank used for driving the gun.

(2) A standard butterfly valve system with a pneumatic actuator located between the storage tank and the breech of the gun, which was designed to valve the high pressure gas from the driving storage tank into the gun to operate it.

(3) Two 4.88 m long, 177.8 mm ID heavywall tubes connected together via a locating ring and flange system, and supported on two heavy I-beams bolted to the floor.

(4) A vent section connected to the muzzle of the gun tube and designed to release the driving pressure from the back of the projectile package.

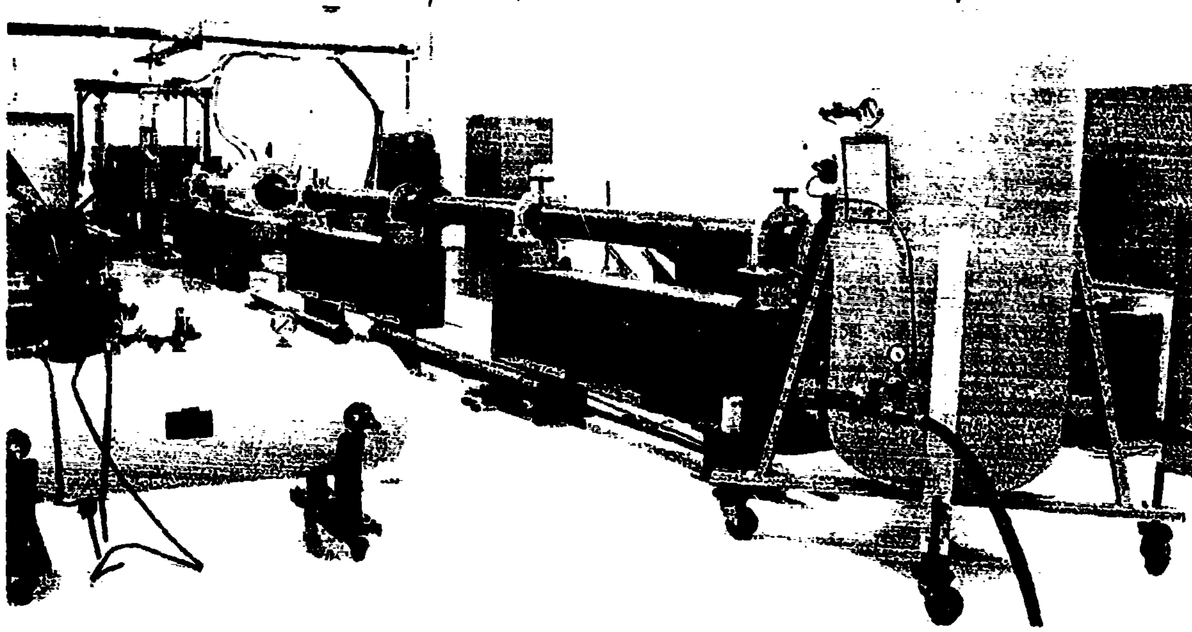

Figure 1. Overall View of 177.8 mm Gun Range

(5) A muffler which encloses the vent section and deflects the venting gases harmlessly toward the floor.

(6) A sabot stripper tube which consists of a steel tube with an initial ID of 177.8 mm that progressively reduces, and has a series of longitudinal wide slots cut into it to facilitate the rapid release of the driving pressure, thus reducing the forces required to decelerate and stop the sabot.

The 177.8 mm gun range was used during this experimental task to launch 450 g spherical bird substitutes onto 0.635 cm flat polycarbonate panels, and 600 g spherical bird substitutes onto a rigid steel target plate. The sphere was placed in a sabot for launching. The sabot was a 177.8 mm OD foam plastic cylinder with a hemispherical cavity in front made to accept the spheres. The diameters of the 450 and 600 g spheres were 97.0 mm and 107.95 mm respectively. These sabots are shown in Figure 2.

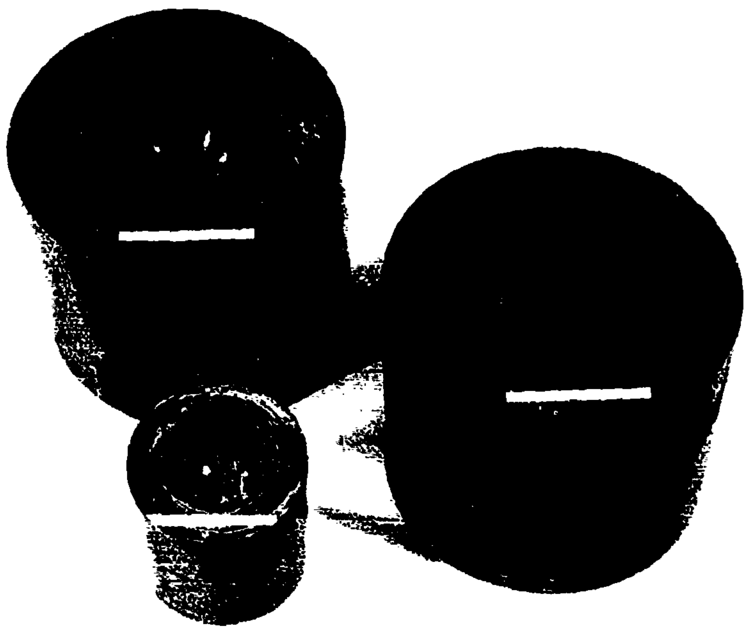

Figure 2. Foam Plastic Sabots Used for Launching Spherical Birds

b. <u>The 88.9 mm Bore Launcher</u>

This launcher was also described in detail by the author in Reference 2. The 88.9 mm bore compressed gas gun consists of a 3.66 m long tube supported on two heavy I-beams bolted to the floor. It uses the same compressor as the 177.8 mm gun, and has a similar storage tank and butterfly valve system with a pneumatic actuator used to drive and operate the gun. A sabot stripper section was attached to the muzzle of the launcher, which consisted of an 88.9 mm ID steel tube with a series of longitudinal slits cut into it. Compression rings were placed around the outside of the tube and the ID was progressively reduced. An overall view of the launcher is shown in Figure 3.

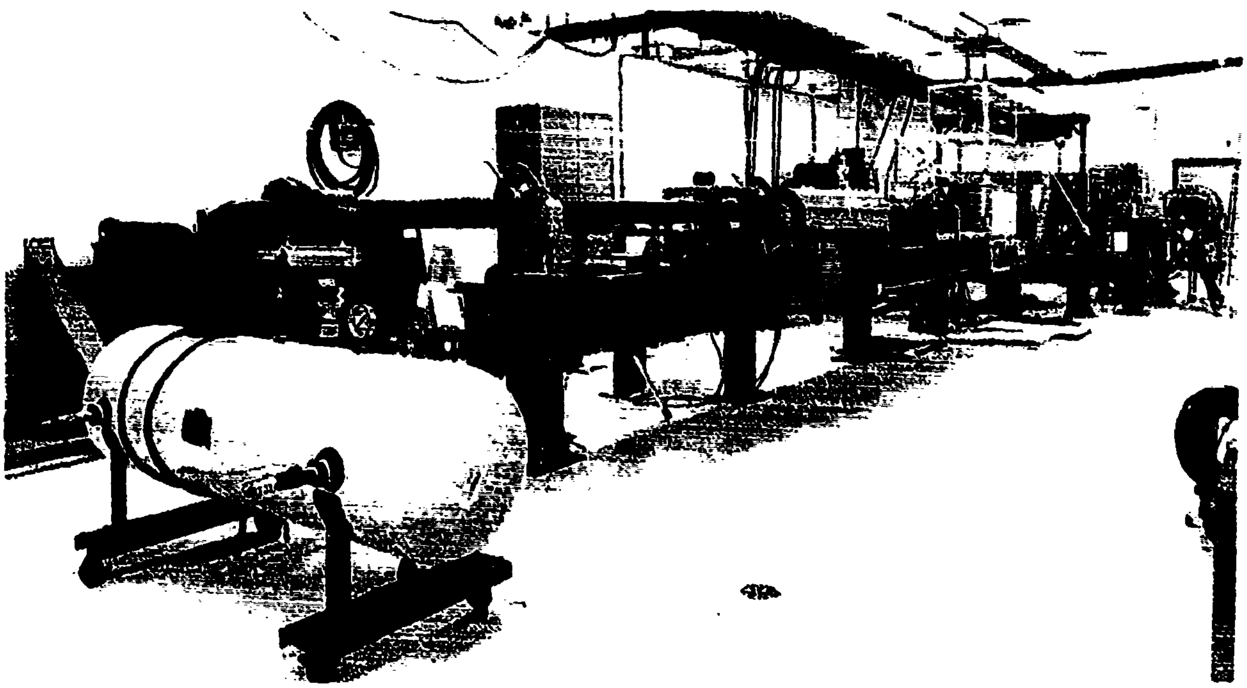

Figure 3. Overall View of the 88.9 mm Gun Range

2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

The 88.9 mm bore compressed gas launcher was used to launch 450 g real birds (pigeons) onto 0.635 cm flat polycarbonate panels and 60 g spherical bird substitutes onto a rigid steel target plate.

2. TARGET DESCRIPTION

Two types of targets were used in this experimental program; flat rigid steel target plates and flat polycarbonate panels. The steel plates were impacted with 60 and 600 g spherical substitute birds and the polycarbonate panels with 450 g real and spherical substitute birds.

The steel plates were used to characterize the impact loads exerted by spherical substitute birds. Two different plates were used; one was installed on the 177.8 mm gun range and was used to characterize the loads of the 600 g spheres. It was a disk, 50.16 cm in diameter and 9.21 cm thick. A series of 0.635 cm holes were drilled along two orthogonal axis of the plate at 2.54 cm intervals. These holes were designed to accept the pressure transducers which were mounted flush with the surface; up to seven transducers were needed to cover the area of impact. The second plate was installed on the 88.9 mm gun range and was used with the 60 g spheres. Like the first plate, it was a steel disk, 30 cm in diameter and 7 cm thick with holes drilled along two orthogonal axis, at 1.27 cm intervals, designed to hold pressure transducers; up to five transducers were needed to cover the area of impact.

The polycarbonate panels were used to investigate the relative damage potential of nominal 450 g real and spherical substitute birds impacting at a 25 degree angle of incidence. The panels were 90 cm long, 60 cm wide, and 0.635 cm thick; and were rigidly attached to a mounting frame which in turn was bolted, at a 25 degree angle to the projectile trajectory, to a structural steel frame. The panels, mounting frame, and structural support are the same used in a previous experimental

program where the effects of bird orientation at impact were studied and reported by Challita in Reference 2. Real birds were tested on the 88.9 mm gun range and spherical substitute birds on the 177.8 mm gun range. Structural frames used with both the 88.9 mm and the 177.8 mm gun range are shown respectively in Figures 4 and 5.

3. VELOCITY AND ORIENTATION MEASUREMENT

The velocity of the bird was measured prior to impact using a simple time-of-flight technique. Between the muzzle of the sabot stripper and the target, two helium/neon laser beams were

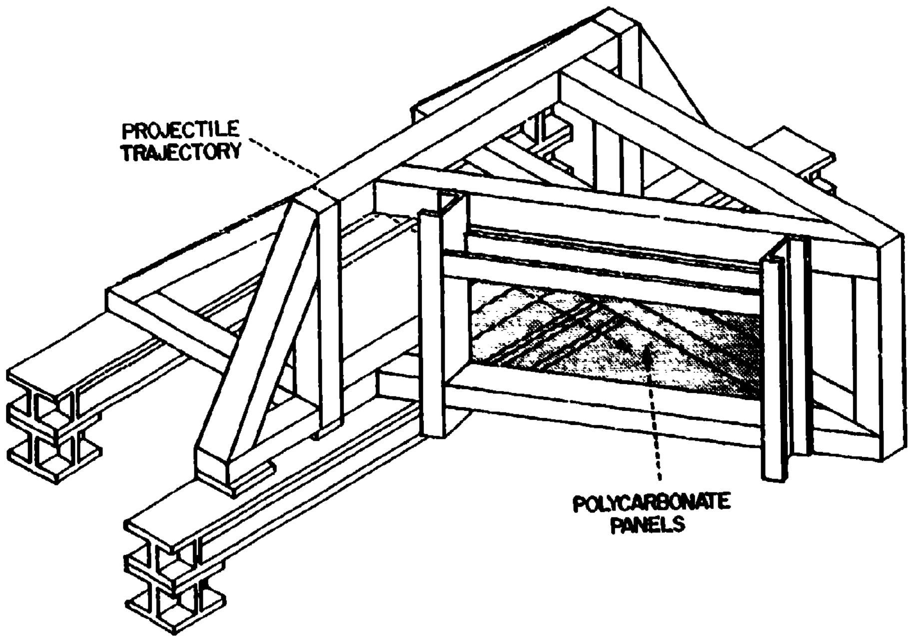

Figure 4. Support Structure and Mounting Frame Used With the 88.9 mm Gun

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2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

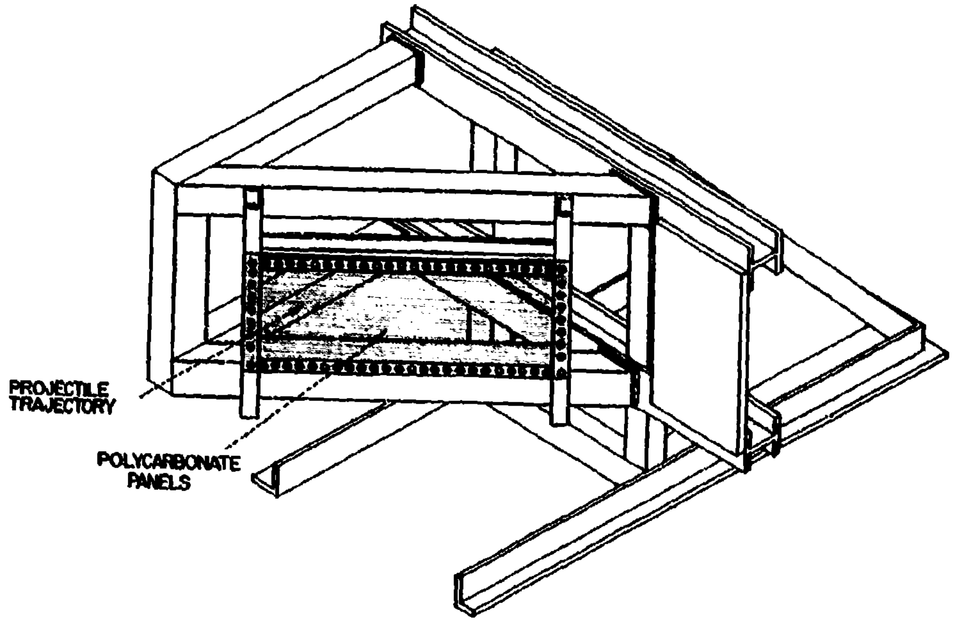

Figure 5. Support Structure and Mounting Frame Used with the 177.8 mm Gun

directed across the trajectory. When the bird interrupted the first laser beam, a counter was started. The counter was stopped when the bird interrupted the second laser beam. The distance between the laser beams and the elapsed time were used to calculate the velocity. To increase the accuracy of the velocity measurements and to monitor bird orientation and integrity prior to impact, two orthogonal pulsed x-ray systems were set up at each laser beam station. The resulting x-radiographs of the bird in flight were used to accurately establish the position of the bird with respect to the laser beams and to monitor the condition and orientation of the bird. This technique proved completely satisfactory for measuring bird velocity and orientation; velocities were measured to within 1 percent, orientation was determined to within 0.5 degrees. A typical x-radiograph of a spherical substitute bird is shown in Figure 6.

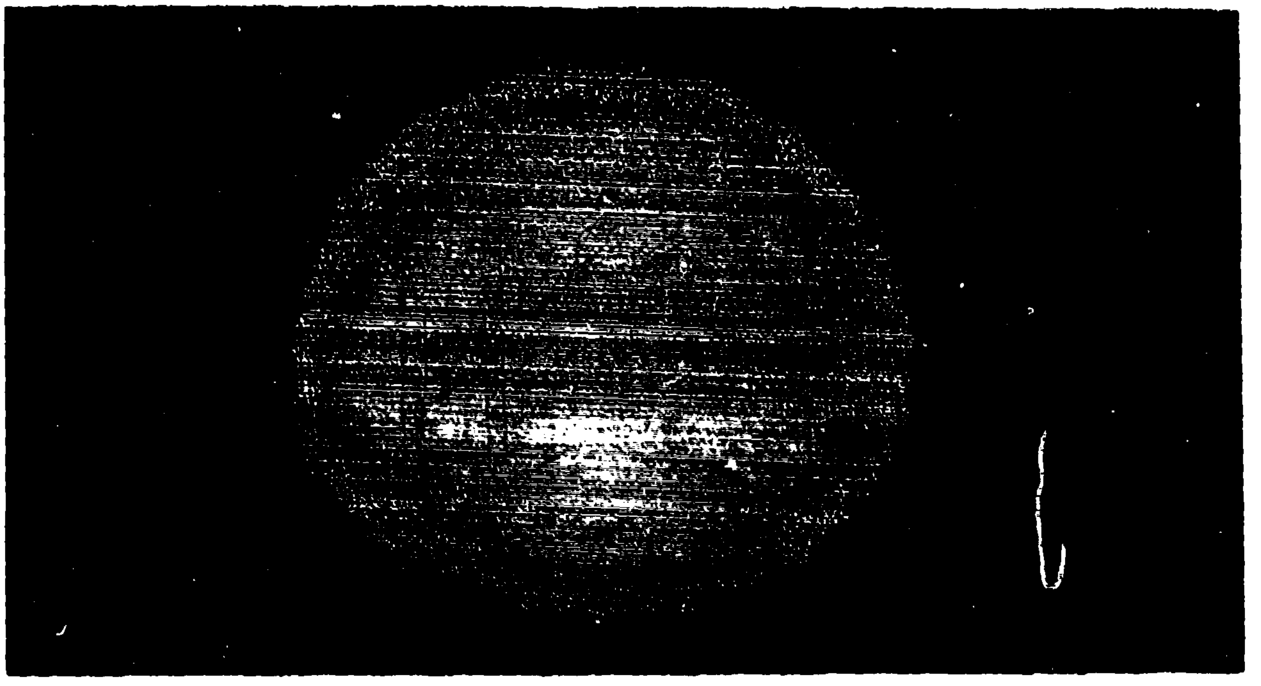

Figure 6. X-radiograph of a Spherical Substitute Bird in Free Flight

In addition to x-radiograph coverage of the bird in flight, high speed motion picture coverage was also obtained for selected shots. Cameras with framing rates of up to 7,000 f/s were employed for specific investigations of the behavior of the bird and panel during impact. Sections of film taken during the first shot conducted with spherical bird substitutes are shown in Figure 7.

4. PRESSURE MEASUREMENTS AND RECORDING

During bird impact, the shock pressure can be extremely high; the duration of the impact is relatively short and there can be important pressure excursions. The pressure sensing devices must be capable of measuring and withstanding these high pressures and the pressure sensing and recording equipment must have adequate bandwidth to detect and record important pressure transients.

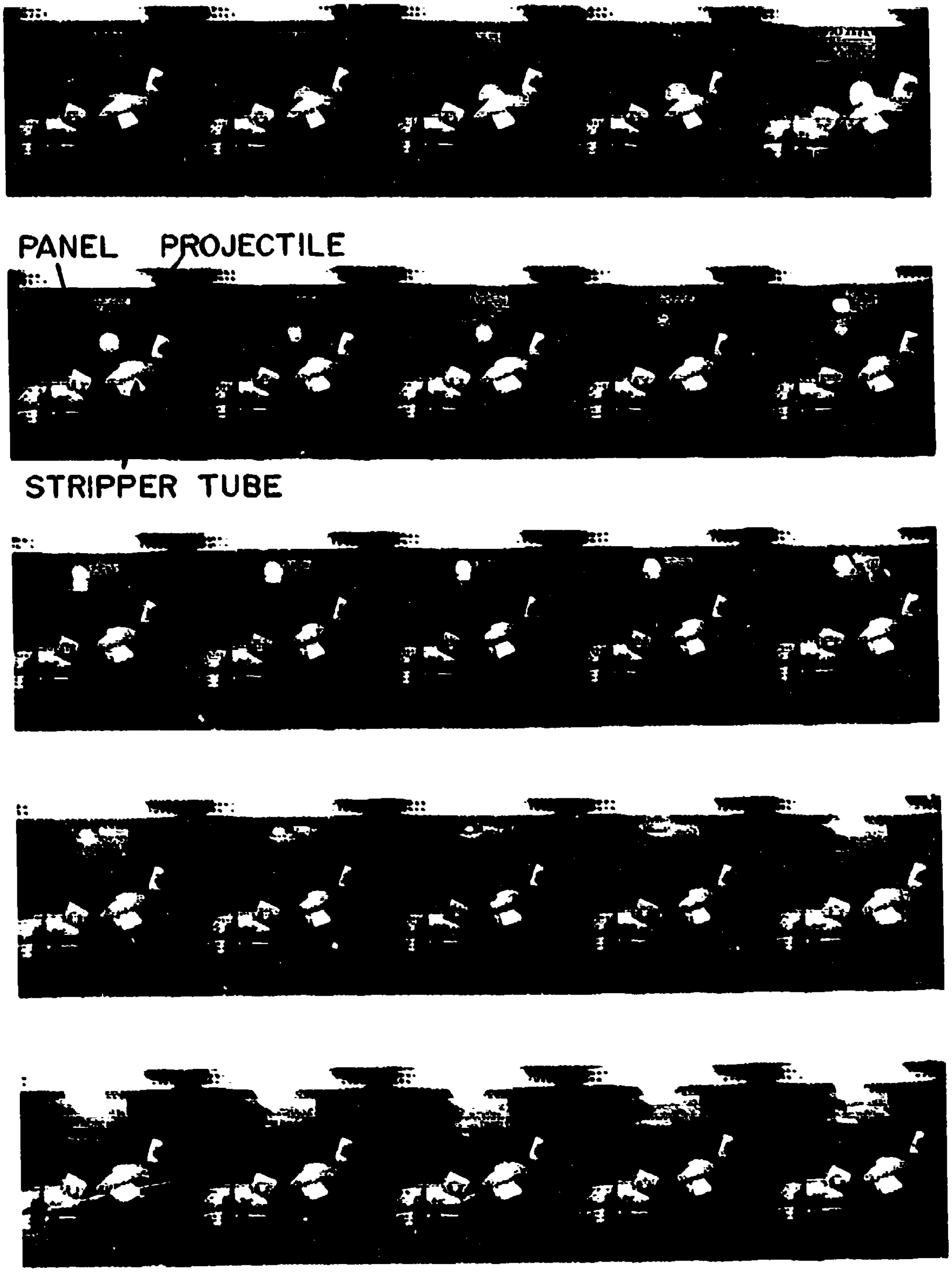

Figure 7. Sections of Film Taken During the First Shot Conducted with Spherical Bird Substitutes

Piezoelectric quartz pressure transducers were used as the basic sensing devices for these experiments. These transducers have a compact impedance converter physically located in the coaxial line close to the crystal; they have a specified pressure range of 0 to 700 MN/m^2, and a specified band width from 0 to 80 kHz. Since these transducers are not specifically designed for impact testing, calibration was necessary to verify their operation. A calibration method for the transducers was developed to verify the applicability of the manufacturer's calibration data to the unidirectional axial loads anticipated. The details of these calibration techniques were reported by Barber in Reference 5. A device was fabricated to enable the unidirectional axial loads similar to bird/plate impact loads to be applied to the transducer. Then, measurements were taken to determine the response of the transducers. It was concluded that the transducers provide reliable, accurate pressure data over the range of pressures and frequencies expected. The transducers were mounted flush with the surface of the steel plates described earlier.

The pressure signals were recorded using an electronic digital memory system. This system uses an analog to digital signal converter. The system has a 300 kHz sample rate, and the capability to store 2048 data points in shift registers on each of ten channels. The analog pressure signals were displayed on an oscilloscope, as a function of time, and the time interval of interest determined. Then, digital data over these intervals were recorded on a cassette and were printed out on an electronic data terminal. This technique significantly increased the accuracy and reliability of the data.

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5. Barber, J.P., J.S. Wilbeck, and H.R. Taylor, "The Characterization of Bird Impacts on a Rigid Plate: Part, I," AFFDL-TR-75-5, AD A021142, January 1975.

SECTION III
EXPERIMENTAL RESULTS

For a substitute bird to be accepted by the transparency design and development community, it has to generate substantially the same impact loads, and produce the same transparency damage as a real bird. Previous studies demonstrated that gelatin with 10 percent porosity is an adequate bird substitute material.

Temporal and spatial loads were measured for right circular cylindrical gelatin substitute birds with length to diameter ratio equal to two. These tests demonstrated that cylindrical birds generate similar loads to real birds when launched with end-on (axial) orientation. But, for many testing circumstances, it would be advantageous to remove orientation as a test variable. Therefore, this program task was undertaken to collect damage data inflicted by spherical substitute birds and real birds to be used in a direct comparison analysis with the data collected in a previous program where damage potential of cylindrical substitute birds was studied. As a result of this analysis, one of the two substitute bird geometries will be recommended for future development and qualification testing of transparencies. To further document and verify the scalability of the large bird data, pressure measurements of 60 and 600 g bird substitutes were also conducted.

1. TARGET DAMAGE STUDIES

The objective of this task was to document and compare the target damage inflicted by spherical substitute birds and real birds as a function of impact location.

A total of 47 shots were conducted in this task; 25 shots with nominal 450 g spherical substitute birds, and 22 shots with nominal 450 g real birds (pigeons). The spheres were 9.7 cm in diameter and had a density of 0.96 g/cm^3, which is similar to

the density of real birds and equal to the density of the 450 g cylindrical substitute birds used in a previous program and reported by Challita in Reference 2. The spheres were molded very homogeneously as can be seen from Figure 8. Projectiles were launched, with end-on orientation, onto a nominal 90 cm long, 60 cm wide, and 0.635 cm thick polycarbonate panel at a 25 degree angle of incidence. The panel was bolted to a relatively rigid support structure as outlined in Section II. Four impact locations were investigated; center panel, down-stream center edge, and up-stream and down-stream corners. These locations, which are shown in Figure 9, were selected to span the range of relatively unconstrained impact (center panel), to constraint on two sides of the impact point (corner impact). The selected conditions generally correspond to conditions present at locations of interest on typical aircraft transparency systems. The panels, support structure,

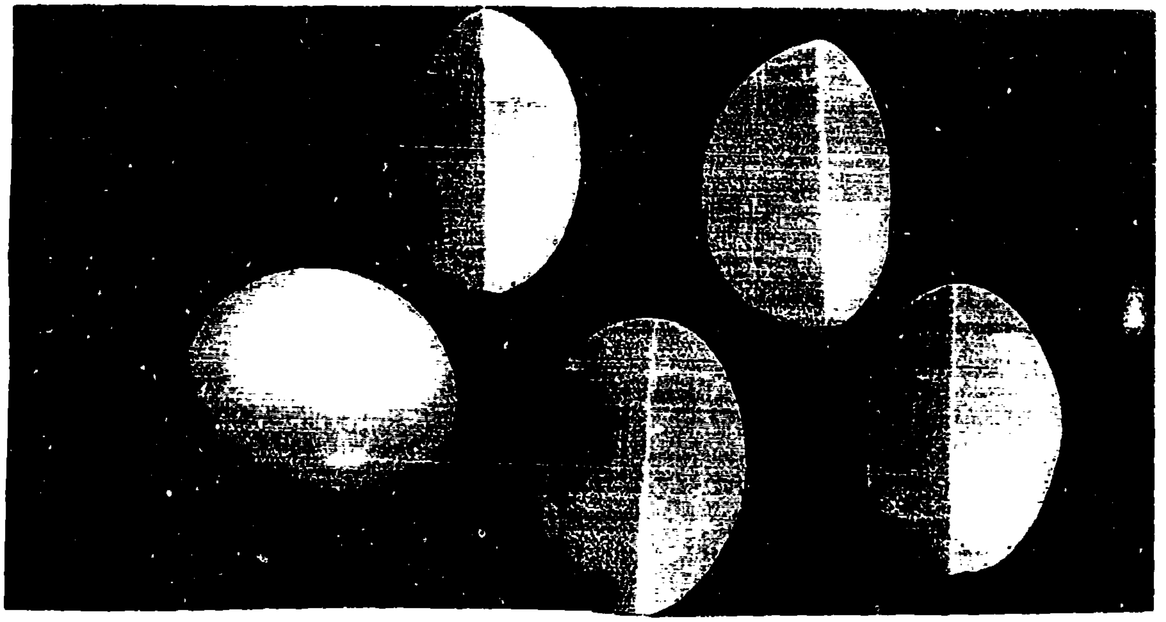

Figure 8. Spherical Substitute Bird Cut into Four Pieces to Show Its Homogeneity

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2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

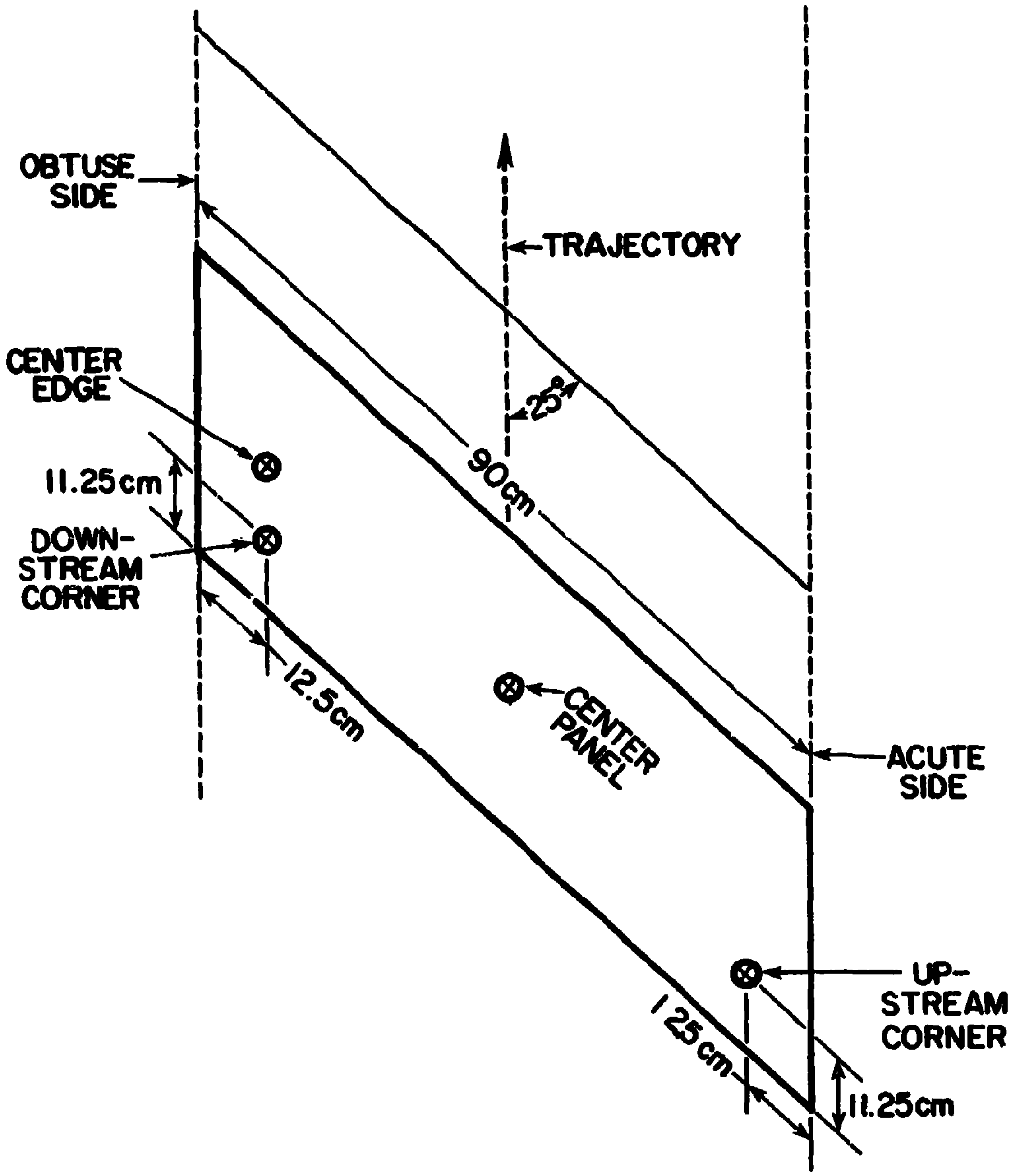

Figure 9. Impact Locations of Real and Substitute Birds onto Polycarbonate Panels.

and impact locations are the same as those used in phase II and reported by Challita in Reference 2.

The ballistic limit, or the minimum perforation velocity, was used as the primary criterion for measuring the target damage. Secondary criteria such as the length of cracks, width and depth of the plastic pocket, and the maximum plastic deformation were used when perforation wasn't achieved. Perforation wasn't achieved at either the center panel or the up-stream corner locations.

a. Summary of Results

A summary of the tests conducted during this experimental program is presented in Table I. Projectile material, impact location, impact velocity, and a description of the resultant target damage are included in Table I. Photographs of the post test panels used to compare the potential damage of the spherical substitute birds and real birds are presented in Appendix A, i.e., photographs of the panels impacted at the center edge and down-stream corner at velocities above and below the threshold velocity, and photographs of panels impacted at the center panel and the up-stream corner that show considerable amount of deformation.

The perforation velocity at the center edge location was found to equal 190 $\pm$ 2 m/s for spherical substitute birds, and 212 $\pm$ 1 m/s for real birds. At the down-stream corner, the perforation velocities were 182 $\pm$ 4 m/s for spherical substitute birds, and 192 $\pm$ 1 m/s for real birds.

Perforation was not achieved at either the center panel location or the up-stream corner location. Examination of the center panel shot numbers 5-0200 and 4-0156 shows that the real bird causes more plastic deformation than the spherical

2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

TABLE I

DAMAGE TEST SUMMARY

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
5-0190	Gelatin Sphere 1. 1b.	Center edge 5" from obtuse	163	Panel broke; 5.5 inch long tear near obtuse edge; yielding along obtuse edge. Panel is believed to have suffered mounting damage before the impact test.
5-0191	"	"	175	Didn't break; 0.7 inch deep, 11.5 inch long, 3.5 inch wide dent near obtuse edge. Yielding along top, bottom and obtuse edges.
5-0192	"	"	202	Panel broke; 9.2 inch long tear near obtuse edge; yielding along top, bottom and obtuse edges.
5-0193	"	"	187	Didn't break; 1.1 inch deep, 12.2 inch long, 3.3 inch wide dent near obtuse edge; yielding along top, bottom and obtuse edges.
5-0194	"	"	197	Panel broke; 8.75 inch long tear near obtuse edge; yielding along bottom and obtuse edges.
5-0195*	"	"	192	Panel broke; 9 inch long tear near obtuse edge; yielding along top, bottom and obtuse edges.
5-0196*	"	"	188	Didn't break; 1 inch deep, 12.7 inch long, 3 inch wide dent near obtuse edge; yielding along top, bottom and obtuse edges.
5-0197*	"	Center panel	304	Didn't break; 12 inch long, 7.2 inch wide and 2 inch deep pocket; yielding along top, bottom and obtuse edges.

TABLE I (Continued)

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
5-0198	Gelatin Sphere 1. lb.	Center panel	325	Panel broke; shattered. Cracks orginated around the bolt holes.
5-0199*	"	"	320	Didn't break; 12.6 inch long, 8.1 inch wide, and 2.5 inch deep pocket; hump at center of impact; yielding along top, bottom and obtuse edges.
5-0200*	"	"	>325	Didn't break; 12.7 inch long, 7.5 inch wide, 2.6 inch deep pocket; hump at center of impact; yielding along top, bottom, and obtuse edges.
5-0201	"	"	296	Didn't break; 11 inch long, 6 inch wide, 2 inch deep pocket; yielding along top, bottom, and obtuse edges.
5-0202	"	"	236	Didn't break; yielding along top, bottom and obtuse edges.
5-0203*	"	Down-stream corner 5" from obtuse 5-3/4" from top.	179	Didn't break; .6 inch deep dent near obtuse edge; yielding along top and obtuse edges.
5-0204	"	"	182	Panel broke; 7 inch long tear near obtuse edge; yielding along top and obtuse edges.
5-0205	"	"	179	Panel broke; 7.5 inch long tear near obtuse edge; yielding along top and obtuse edges.

TABLE I (Continued)

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
5-0206	Gelatin Sphere 1. lb.	Down-stream corner 5" from obtuse 5-3/4" from top	176	Didn't break; .7 inch deep dent near obtuse edge; yielding along top and obtuse edges.
5-0207	"	"	182	Didn't break; .85 inch deep dent near obtuse edge; yielding along top and obtuse edges.
5-0208*	"	"	186	Panel broke; 8 inch long tear near obtuse edge; yielding along top and obtuse edges.
5-0209	"	"	185	Didn't break; .76 deep dent near obtuse edge; yielding along top and obtuse edges.
5-0210*	"	Up-stream corner 5" from acute, 5-3/4" from bottom	305	Didn't break; 11.2 inch long, 6.3 wide and 1.8 inch deep pocket; yielding along top, acute and obtuse edges.
5-0211*	"	"	321	Didn't break; 12.5 inch long 6.5 inch wide and 2. inch deep pocket with a hump at the center of pocket; yielding along top, bottom, acute and obtuse edges.
5-0212	"	"	291	Didn't break; 9.7 inch long, 6 inch wide and 1.3 inch deep pocket with a hump at center of impact; yielding along top, bottom and acute edges.

TABLE I (Continued)

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
5-0213	Gelatin Sphere	Up-stream corner 5" from acute, 5-3/4" from bottom	316	Didnt break; 12 inch long 6.7 inch wide and 1.8 inch deep pocket with a hump at center of impact; yielding along top, bottom and acute edges.
5-0214	"	"	24[illegible]	Didn't break; yielding along top and obtuse edges.
4-0146	Piegeon (.8 lb.)	Center edge 5" from obtuse	235	Didn't break; .7 inch dent near obtuse edge; yielding along top, bottom and obtuse edges.
4-0147*	Pigeon (1.1b.)	"	213	Panel broke; 9.5 inch long tear near obtuse edge; yielding along top, bottom and edges.
4-0148	Pigeon (1. lb.) 20% water	"	217	Panel broke; 10 inch long tear near obtuse edge; yielding along top, bottom and obtuse edges.
4-0149	Pigeon (1. lb.)	"	223	Panel broke; 7 inch long tear near obtuse edge; yielding along top, bottom and obtuse edges.
4-0150*	Pigeon (1. lb.)	"	211	Didn't break; 1.3 inch deep dent near obtuse edge; yielding along top, bottom and obtuse edges.
4-0151	"	"	205	Didn't break; 1.4 inch deep dent near obtuse edge; yielding along top, bottom and obtuse edges.

TABLE I (Continued)

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
4-0152	Pigeon (1. lb.)	Center edge 5" from obtuse	210	Panel broke; 9.7 inch long tear near obtuse edge; yielding along top, bottom and obtuse edges.
4-0155	"	Center panel	314	Panel broke; shattered; cracks and failure originated along bolt holes.
4-0156*	"	"	308	Didn't break; 12 inch long, 7 inch wide and 2.85 inch deep pocket; finger-shaped ridges along edge of pocket; yielding along top, bottom and obtuse edges.
4-0157*	"	"	313	Didn't break; 9.3 inch long, 6.7 inch wide and 2.3 inch deep pocket; yielding along bottom and obtuse edges.
4-0158*	"	"	294	Didn't break; 7.6 inch long, 5.5 inch wide and 2.2 inch deep pocket; yielding along top, bottom and obtuse edges.
4-0159	"	"	234	Didn't break; yielding along top and obtuse edges.
4-0160*	"	Down-stream corner; 5" from obtuse, 5-3/4" from bottom	191	Didn't break; 1.2 inch deep dent near obtuse edge; yielding along bottom and obtuse edges.
4-0161	"	"	206	Panel broke; 7 inch long tear near obtuse edge; yielding along bottom and obtuse edges.

TABLE I (Concluded)

SHOT NUMBER	PROJECTILE MATERIAL AND SHAPE	IMPACT LOCATION	VELOCITY (m/s)	PANEL POST TEST CONDITION
4-0162*	Pigeon (1. lb.)	Down-stream corner; 5" from obtuse, 5-3/4" from bottom	193	Panel broke; 6.7 inch long tear near obtuse edge; yielding along bottom and obtuse edges.
4-0163	"	"	189	Didn't break; .95 inch deep dent near obtuse edge; yielding along bottom and obtuse edges.
4-0164*	"	Up-stream corner 5" from acute 5-3/4" from bottom	308	Didn't break; 14 inch, 9 inch wide and 3.25 inch deep pocket with a hump at center of pocket; finger-shaped ridges along side of pocket; yielding along bottom and acute edges.
4-0165*	"	"	306	Didn't break; 14 inch long, 8.4 inch wide and 2.8 inch deep pocket with hump at center of pocket; finger-shaped ridges along side of pocket; yielding along bottom and acute edges.
4-0166	"	"	290	Didn't break; 10 inch long, 6.2 inch wide and 2.3 inch deep pocket, yielding along bottom and acute edges.
4-0167	"	"	232	Didn't break; yielding along bottom and acute edges.

*Photographs of these shot numbers are presented in Appendix A.

bird; even though the spherical substitute bird was launched 20 m/s faster than the real bird. Similarly, examination of the up-stream corner shot numbers 5-0211 and 4-0164 (spherical substitute bird was 13 m/s faster than the real bird) clearly indicates that the real bird causes more plastic deformation than the spherical substitute bird.

b. Comparison of Damage Inflicted by Real and Substitute Birds

The objective of this study was to conduct a direct comparison of the post-test panels, impacted by real and substitute birds, in order to recommend a substitute bird for development and proof testing of transparencies.

Polycarbonate panels were impacted with three different projectiles (right circular cylinders, spheres, and real birds) and five sets of damage data were collected. In a previous experimental program, reported by Challita in Reference 2, right circular cylinders were launched onto polycarbonate panels with three different orientations in order to study the effects of orientation at impact on damage level. Perforation velocity was used, when applicable, as the main criterion for damage comparison. A summary of the perforation velocities for various projectile materials and orientations are presented in Table II. In Reference 2, right circular cylinders with end-on orientation were found to be the most damaging orientation; therefore, our comparison will be limited to right circular cylinders with end-on orientation.

Prior to discussing the results of this comparison, some factors affecting these results should be pointed out. First, it should be noted that the time-loading histories of the panel during a spherical impact and a real bird impact or

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2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

TABLE II

THRESHOLD VELOCITIES OF 1/4" POLYCARBONATE PANELS

IMPACT LOCATION	PROJECTILE MATERIAL AND ORIENTATION				
	RIGHT CIRCULAR CYLINDERS			SPHERICAL BIRD SUBSTITUTES	REAL BIRDS (PIGEONS)
	END-ON	FLAT-ON	SIDE-ON		
Center edge 5" from obtuse	208 ± 4 m/s	204 ± 2 m/s	211 ± 1 m/s	190 ± 2 m/s	212 ± 1 m/s
Down-stream corner	173 ± 2 m/s	184 ± 3 m/s	234 ± 2 m/s	182 ± 4 m/s	192 ± 1 m/s

an end-on cylinder impact are different. The impact duration of a sphere is shorter than the impact duration of a real bird or an end-on cylinder of the same mass, density, and velocity. The impact duration is directly proportional to the effective bird length which is smaller for spheres than it is for real birds and end-on cylinders. Also, the loaded area during impact is larger for a sphere than it is for a real bird or end-on cylinder. Thus, for similar energy level impacts, the spheres generate higher strain rates in the material, and consequently, it should be expected to see different structure-panel response from real bird or end-on cylinder impacts to spherical impacts.

The comparison will be conducted as a function of impact location. Each location will be considered separately and the damage potential of various projectiles will be evaluated.

Center edge:

Panels impacted with real birds and end-on cylinders showed very similar deformation and perforation velocity. Panels impacted with spheres showed less total plastic deformation and had lower perforation velocity than both real birds and end-on cylinders. The plastically deformed surface of the panel impacted with a sphere was not as smooth as for the other two cases. This may be attributed to the strain rate sensitivity of the panel. For similar input of energy levels, spheres exhibit higher strain rates during impact because of their shorter impact duration. Impact duration is directly proportional to the effective bird length which is equal to 23.1 cm for spheres and 28.5 cm for end-on cylinders (for a 25 degree impact angle).

Down-stream corner:

Panels impacted with end-on cylinders have the lowest perforation velocity. These panels showed more plastic flow than gelatin spheres. They have deeper pockets at lower energy levels.

Panels impacted with real birds showed the most plastic flow; but they were at higher energy levels than the end-on cylinders and spheres.

Panels impacted with spheres showed similar deformation and perforation velocity to panels impacted with flat-on cylinders. The plastically deformed surfaces were not as smooth as either real birds or end-on cylinders.

Center panel:

Panels impacted with gelatin spheres had less plastic deformation than panels impacted with end-on cylinders or real birds, even though the spherical impacts were at higher energy levels.

Panels impacted with real birds at velocities higher than 300 m/s showed slightly more pronounced finger-shaped ridges (local buckling) than panels impacted with end-on cylinders. This is another situation where the panel sensitivity to strain rate might have had an effect on the damage. It was observed that at velocities higher than 300 m/s the cylinders stretch to an in-flight $L/D > 2$. Real birds had an in-flight $L/D = 2$.

Up-stream corner:

Panels impacted with spheres exhibited the least amount of plastic deformation compared to panels impacted with real birds and end-on cylinders. Real birds produced more pronounced finger-shaped ridges, around the plastic pockets, than end-on cylinders. No ridges were observed with spherical impacts. At the highest velocity launched, real birds produced deep pockets compared to the pockets by end-on cylinders. The end-on cylinders produced wider pockets.

The damage comparison at the center panel and upstream corner shows that spheres cause less plastic deformation than real birds and cylindrical substitute birds, and the damage

comparison at the center edge and down-stream corner shows that spheres have lower perforation velocity than real birds. The latter result was attributed to the strain rate sensitivity of the panel (spherical impacts generate higher strain rates than end-on or cylindrical impacts) and to the structure-panel response (edge effects). Spherical substitute birds hit the panel a lot closer to the edge than real birds and cylindrical substitute birds; i.e., spheres hit approximately 0.5 in. from the edge compared to 1.8 in. for end-on cylinder. This is mainly because its diameter is larger than the other two (Figures 10 and 11).

The results of this comparison can be summarized as:

(1) End-on cylinders cause similar damage to real birds and are more damaging than spheres at the center panel and the up-stream corner locations.

(2) End-on cylinders are as damaging as real birds on the center edge location and more damaging than real birds at the down-stream corner.

(3) Spheres have lower perforation velocity than real birds at the down-stream corner and center edge locations and have lower perforation velocity than end-on cylinders at the center edge. This is attributed to the edge effects and to the strain rate sensitivity of the panel.

(4) Irregularities in the plastically deformed region decrease with increasing impact duration. Thus, longer projectiles result in smoother deformation.

2. SPHERICAL SUBSTITUTE BIRD LOADING STUDIES

A total of 55 shots were performed to investigate and document the effects of geometry on impact loading. The projectiles used were 60 and 600 g spherical substitute birds (gelatin with 10 percent porosity). Projectiles were launched

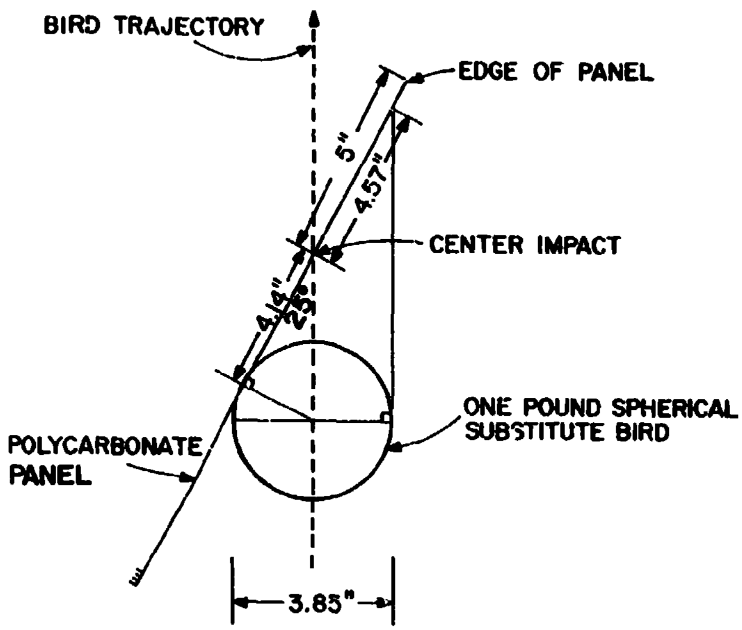

Figure 10. Projection of a 1-lb. Spherical Substitute Bird onto a Polycarbonate Panel at 25° Angle of Incidence when Impacting the Center Edge Location

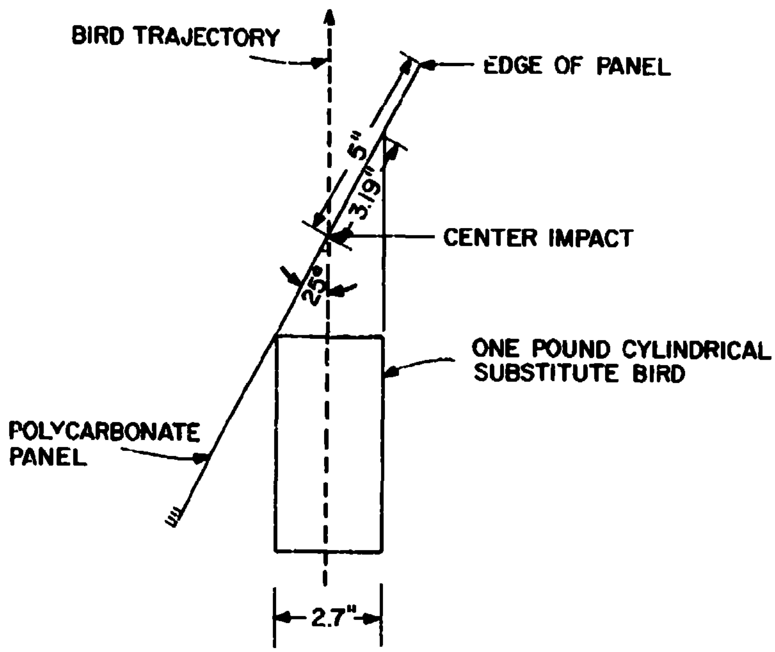

Figure 11. Projection of a 1-lb. Cylindrical Substitute Bird with End-on Orientation onto a Polycarbonate Panel at 25° Angle of Incidence when Impacting the Center Edge Location.

at velocities of 100, 200, and 300 m/s onto a steel target plate at three impact angles; 90, 45, and 25 degrees.

Time varying pressure data were collected using a digital memory system as described in Section II. Peak pressure and impact duration were measured from these recorded data. The results of these measurements, together with comparisons to theoretical predictions are presented in the following sections.

a. Pressure-time History

Bird impact on a rigid plate can be characterized as a fluid dynamic process having four distinct phases. The first phase is the initial impact phase during which very high shock pressures are generated between the bird and the target. The release of the shocked material results in a decaying pressure during phase two. The shock pressure decays to a steady-state pressure which characterizes phase three. During this phase, the bird flows steadily onto the plate and is regarded as jet flow. The fourth phase of the impact occurs when the trailing end of the bird approaches the plate and the pressure drops to zero. These phases were discussed in detail in Reference 4 by Barber, Reference 3 by Challita, and Reference 1 by Wilbeck and were found adequate to describe the impact of a real bird and cylindrical substitute bird with length to diameter ratio equal to two when launched with end-on orientation on a rigid plate.

Typical pressure traces of spherical substitute birds impacting a rigid steel target plate at normal and oblique

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1. Wilbeck, J.S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.

3. Challita, A., and J.P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.

4. Barber, J.P., J.S. Wilbeck, and H.R. Taylor, "Bird Impact Forces and Pressures on Rigid and Compliant Targets," AFFDL-TR-77-60, May 1978.

angles of incidence are presented in Figures 12 and 13. A peak pressure rise and decay can be seen on these traces. Unlike the real or cylindrical substitute bird impacts, no plateau indicative of steady-state flow is observed.

During the initial impact, the particles on the front surface of the projectile are instantaneously brought to rest relative to the target face and a shock wave propagates into the projectile. As this shock wave propagates into the projectile, it brings the material behind the shock to rest. The pressure in the compressed region is initially very high and uniform across the impact area. The outer surface of the projectile is a free surface and the material near this surface is subjected to a very high stress gradient. This stress gradient causes the material to accelerate radially outward and a release wave is formed and propagates inward. The arrival of this release wave at the center of impact marks the end of the initial impact and the beginning of the decay process. The pressure behind the shock, or the Hugoniot pressure, depends on the projectile density, shock velocity, and the impact velocity. The Hugoniot pressure was derived by Wilbeck in Reference 1 and is given by:

$$P_H = \rho V_s V_n$$

where: ρ = density of the projectile

V_s = shock velocity

V_n = normal component of the impact velocity

V_n is equal to the impact velocity, V, for normal impacts, and equal to V sin θ for oblique impacts (θ is the impact angle). The shock velocity, V_s, corresponding to the normal component of the impact velocity V_n should be used for oblique impacts. Wilbeck in Reference 1 derived the relation between the shock

1. Wilbeck, J.S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.

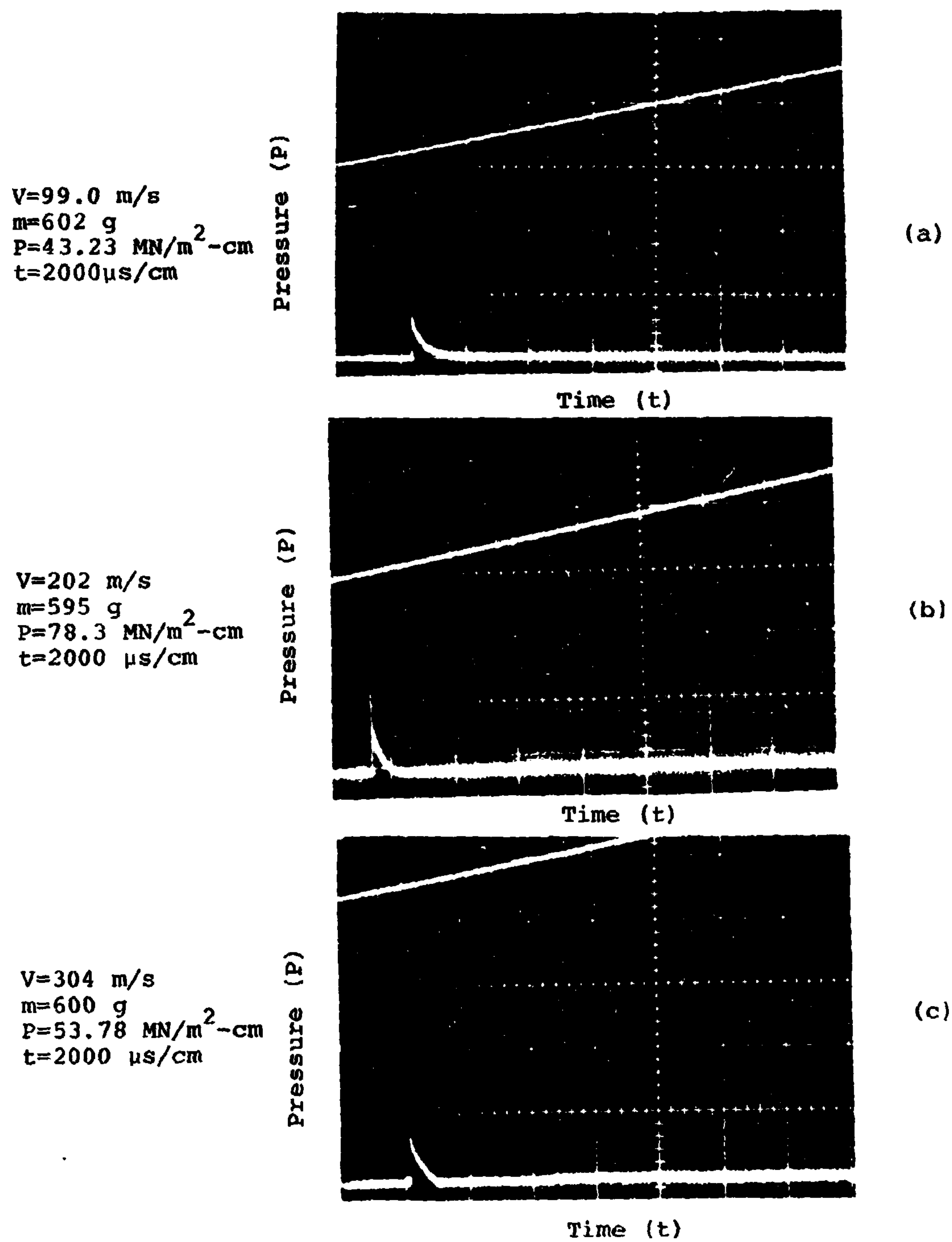

Figure 12. Typical Pressure-Time Record of Nominal 600 g Spherical Substitute Bird (Gelatin with 10 Percent Porosity). (a) 90° impact, center transducer; (b) 45° impact, 3" below center; (c) 25° impact, 2" below center

V=196 m/s
m=60 g
P=44.5 MN/m^2-cm
t=2000 μs/cm

(a)

V=285 m/s
m=60 g
P=43.0 MN/m^2-cm
t=2000 μs/cm

(b)

V=297 m/s
m=60 g
P=21.3 MN/m^2-cm
t=2000 μs/cm

(c)

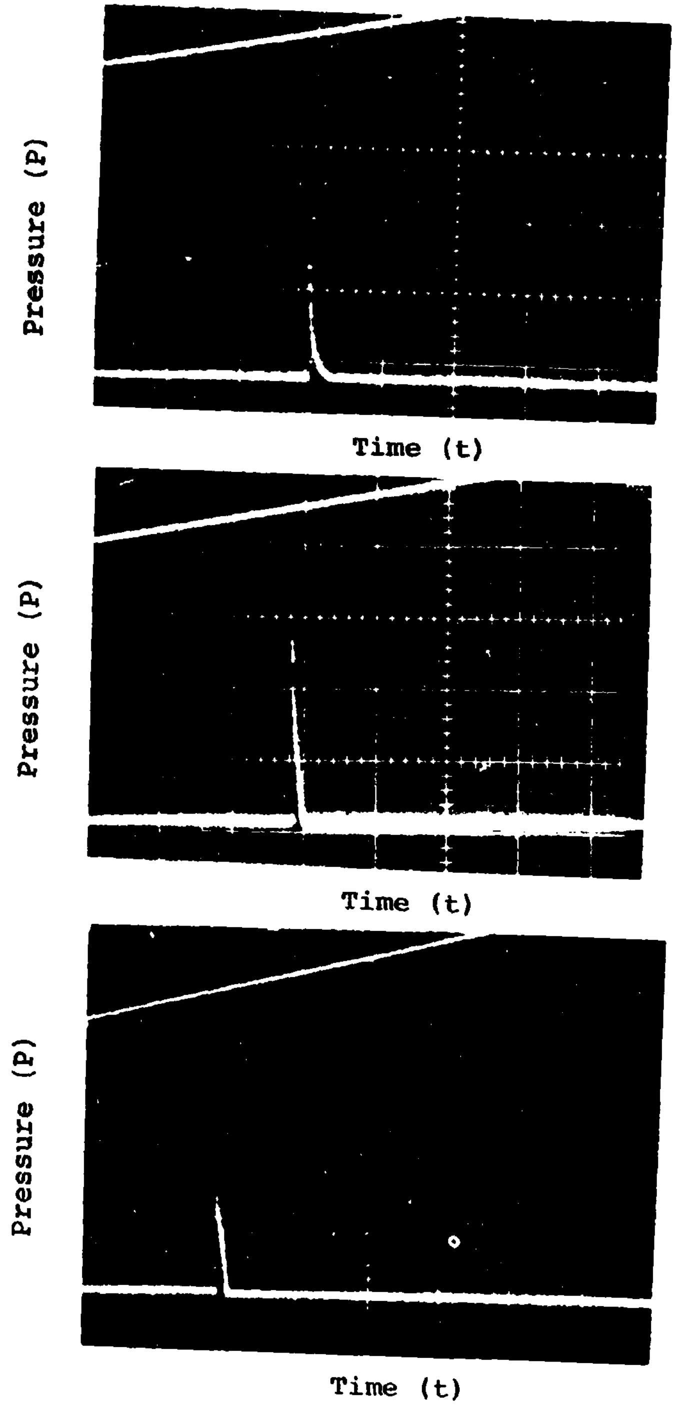

Figure 13. Typical Pressure-Time Record of Nominal 60 g Spherical Substitute Bird (Gelatin with 10 Percent Porosity). (a) 90° impact; center transducer; (b) 45° impact; 2" below center; (c) 25° impact; 3" below center

velocity and the impact velocity for gelatin with 10 percent porosity.

The initial impact pressures measured for all normal and oblique impacts of 60 and 600 g gelatin spheres are presented along with the corresponding theoretical Hugoniot pressure in Figures 14, 15, and 16. The measured impact pressures for the 600 g spheres agree fairly well with the theoretical Hugoniot pressure for all impact angles. The measured impact pressures for the 60 g spheres were, as expected, lower than the calculated values. This departure from predictions is attributed to the limited bandwidth (80 kHz) of the pressure transducers used. Peaks may have been clipped because of the relatively shorter duration of the shock pulse in these impacts which is a function of the size of the projectile and the impact velocity.

As the shock propagates into the projectile, a radial release wave propagates in toward the center of the projectile from the free surface edges, and a decay process is formed when the release waves converge at the center of impact. In an end-on cylinder or real bird impact, the decay process is over well before the trailing end of the bird reaches the target, and a steady-state flow is established. The steady flow is finally terminated when the end of the bird reaches the target. In contrast, Hugoniot pressure is still decaying as the trailing edge of the spherical substitute bird reaches the target. This can be seen from the pressure traces in Figures 12 and 13 where the shock pressure decays to zero and no pressure plateau indicative of the steady-state process is observed.

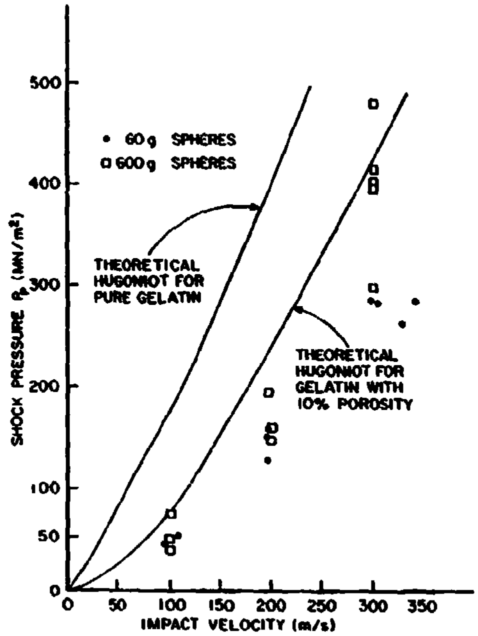

Figure 14. Comparison of Measured Peak Pressures to Theoretical Hugoniot for 60 and 600 g Spherical Substitute Bird at Normal Impact

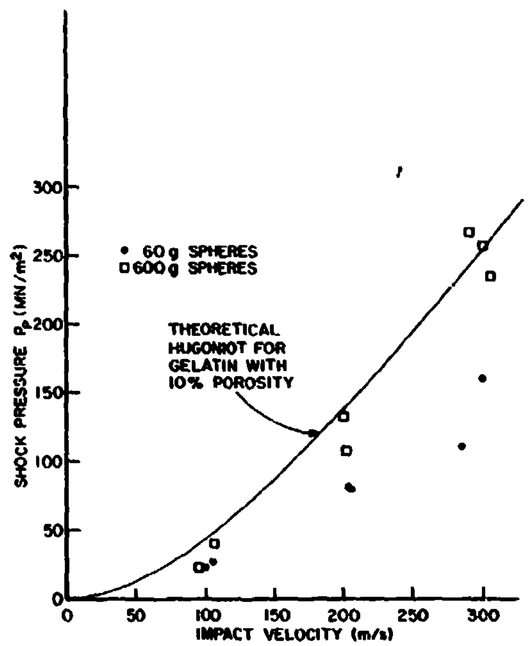

Figure 15. Comparison of Measured Peak Pressures to Theoretical Hugoniot for 60 and 600 g Spherical Substitute Bird at 45° Impact

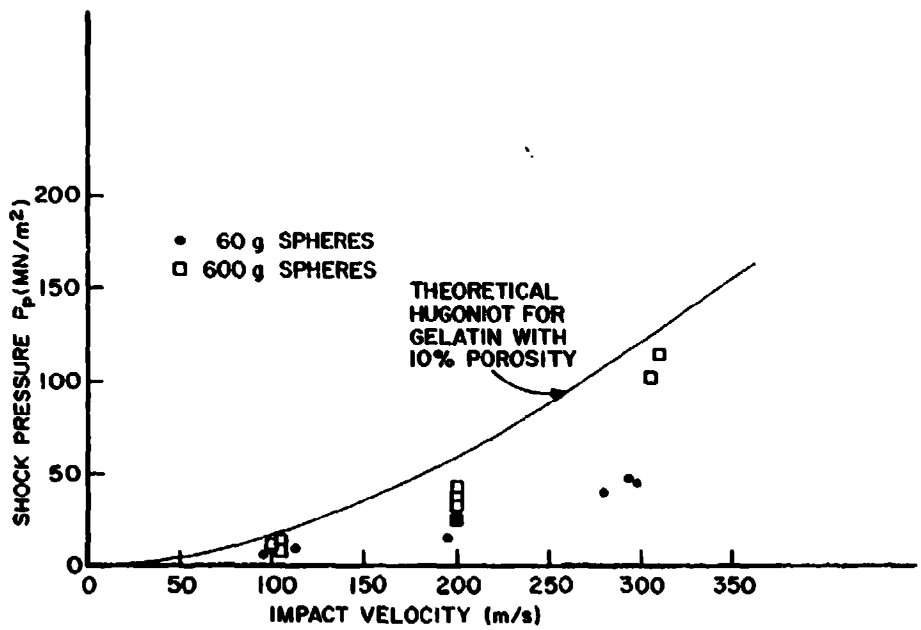

Figure 16. Comparison of Measured Peak Pressures to Theoretical Hugoniot for 60 and 600 g Spherical Substitute Bird at 25° Impact

SECTION IV
CONCLUSIONS AND DISCUSSION

A large and detailed body of impact pressure and damage potential data now exists for real birds and bird substitutes (gelatin with 10 percent porosity) over an enormous range of impact parameters. The parameters and their ranges are:

(1) Real and substitute bird mass - 60 g to 3600 g.

(2) Impact velocity - 50 m/s to 325 m/s.

(3) Impact angle - 25, 45, and 90 degrees.

(4) Geometry of substitute bird - right circular cylinders with L/D = 2 and spheres.

(5) Orientation of cylindrical substitute birds at impact - end-on, flat-on, and side-on.

(6) Target - rigid and compliant.

This entire body of data has been analyzed and the important impact processes identified, functional relationships between the impact pressures and impact parameters identified, scaling of impact loads with bird mass concluded, effects of orientation at impact studied and worst-case orientation identified, and comparisons of damage potential of real and substitute birds completed. From the work reported here, the following conclusions may be drawn.

(1) Gelatin with 10 percent porosity is an adequate substitute bird material.

(2) Impact pressure measurements of spherical substitute birds did not exhibit any steady-state flow condition.

(3) Of the three projectiles tested (end-on real birds, spheres, and end-on right circular cylinders) spheres produced the least amount of plastic deformation at the center and up-stream corner locations.

(4) Spheres had the lowest perforation velocity at the center edge and had a lower perforation velocity than end-on real birds at the down-stream corner. This was attributed to the edge effects and to the strain rate sensitivity of the panels tested.

(5) End-on cylinders showed similar perforation velocities and damage potential to end-on real birds.

(6) End-on cylinders are better substitute birds than spheres.

For convenience and completeness of the report, a summary of the conclusions and findings reported in previous work by Challita in References 2 and 3, by Barber in References 4 and 5, by Wilbeck in Reference 1, and by Bauer in Reference 6 will be listed here.

(1) Real birds behave as a fluid during impact at the impact velocities of interest in birdstrike (>75 m/s).

(2) There are four phases of fluid behavior during a real and end-on cylindrical substitute bird impact event; the shock phase of initial impact, shock pressure decay, steady flow, and termination.

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1. Wilbeck, J.S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.
2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.
3. Challita, A., and J.P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.
4. Barber, J.P., J.S. Wilbeck, and H.R. Taylor, "Bird Impact Forces and Pressures on Rigid and Compliant Targets," AFFDL-TR-77-60, May 1978.
5. Barber, J.P., H.R. Taylor, J.S. Wilbeck, "Characterization of Bird Impacts on a Rigid Plate: Part I," AFFDL-TR-75-5, January 1975.
6. Bauer, D.P. and J.P. Barber, "Experimental Investigation of Impact Pressures Caused by Gelatin Simulated Birds and Ice," UDR-TR-78-114, November 1978.

(3) Peak shock pressures are independent of bird mass but depend in a predictable manner on impact velocity, impact angle, and bird material properties.

(4) Steady flow pressures are independent of bird mass but depend in a predictable way on impact velocity, impact angle and bird material properties.

(5) The spatial distribution of bird impact pressures scale linearly with bird dimensions (providing bird orientation at impact is fixed).

(6) Impact duration is given by simply dividing the "effective bird length," which is a function of impact angle and bird orientation, by the impact velocity.

(7) Of the three impact orientations of the right circular cylinders tested (end-on, flat-on, and side-on) side-on was the least critical and end-on was the most critical orientation.

(8) During end-on birdstrike testing pitch and/or yaw of the bird would tend to decrease criticality.

SECTION V
RECOMMENDATIONS

It is recommended that:

(1) Right circular cylinders with length-to-diameter ratio equal to two be used as the substitute bird for all developmental and qualification testing of transparencies.

(2) Gelatin with 10 percent porosity be used as the substitute bird material. The bird substitute specifications are preserted in Appendix B.

(3) Additional damage tests be conducted as a function of edge proximity to give the designer a better insight on the transparency-structure response.

(4) A research program be conducted using larger birds to determine the perforation velocities for the center panel and up-stream corner locations to eliminate any doubt about the similarity of the damage potential of the end-on cylinders and real birds.

APPENDIX A

PHOTOGRAPHS OF DAMAGED PANELS

(a)

(b)

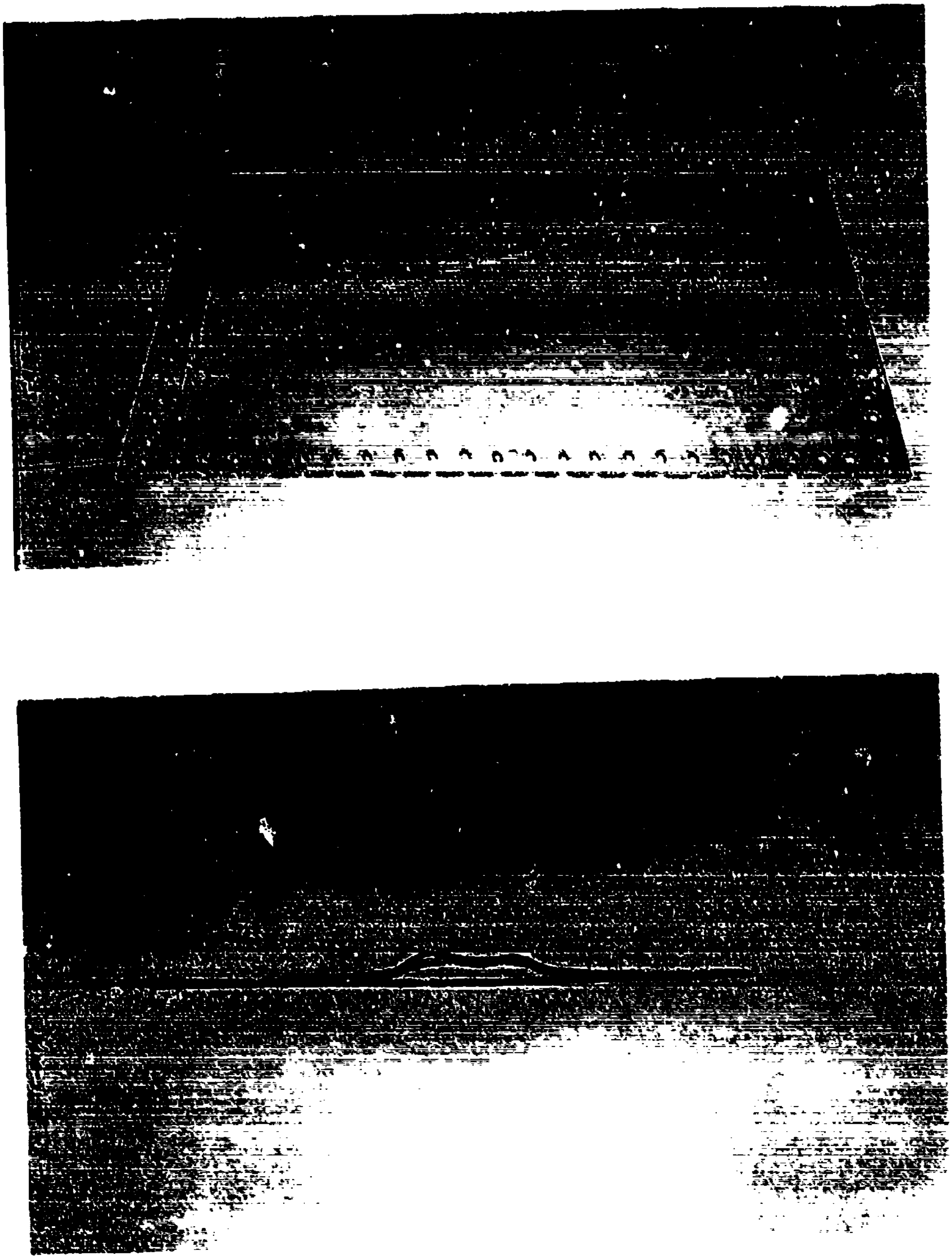
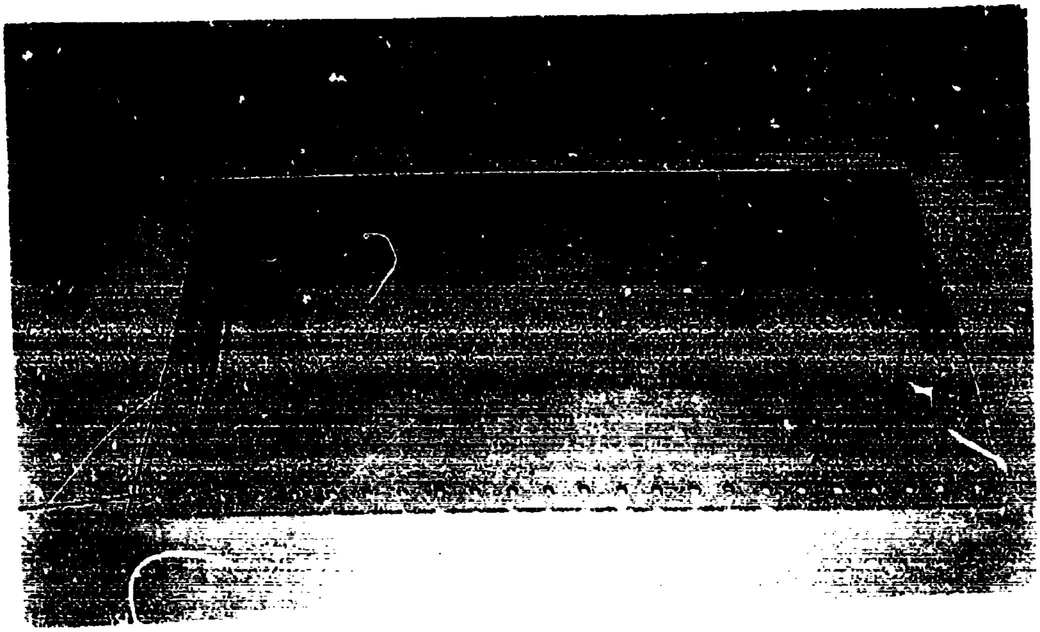


Figure A-1. Shot No. 5-0195; Panel Impacted at the Center Edge; One-Pound Spherical Gelatin Launched at 192 m/s. (a) front view; (b) end view

(a)



(b)

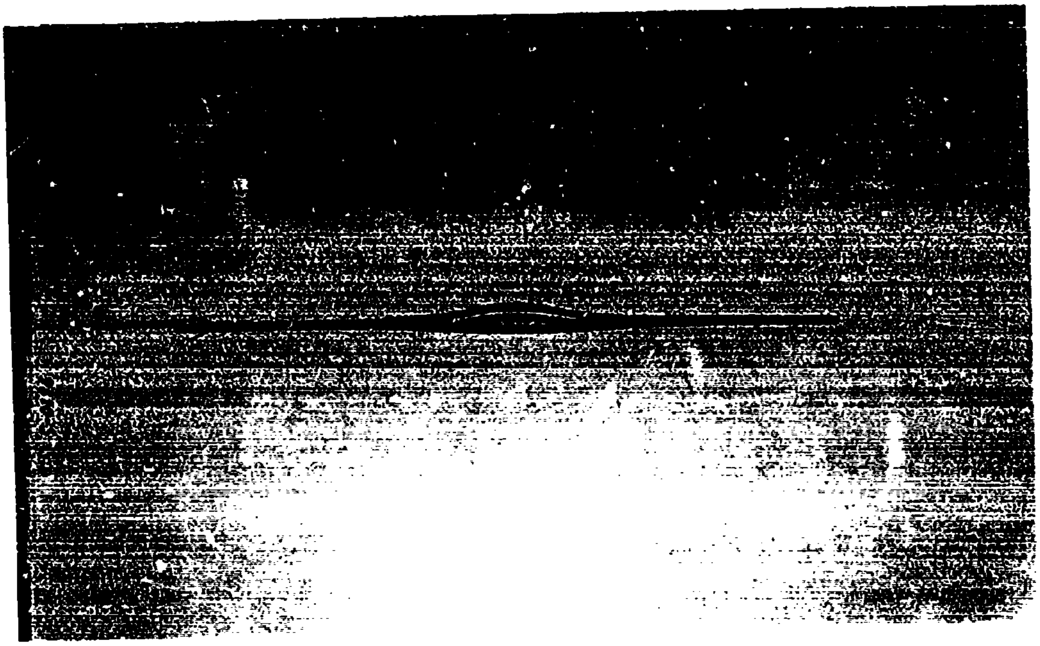
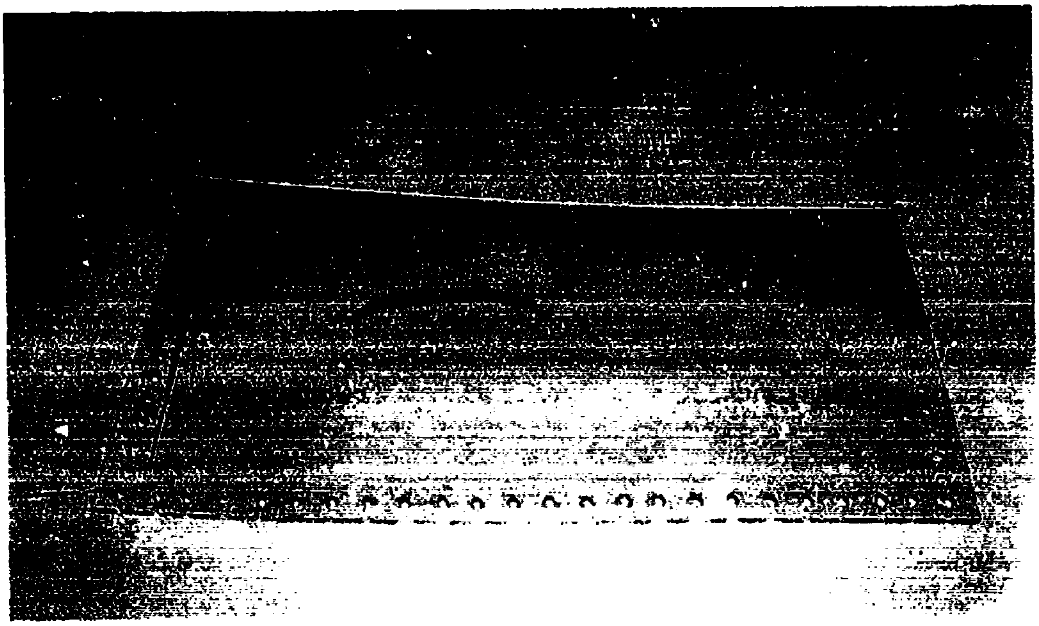


Figure A-2. Shot No. 5-0196; Panel Impacted at the Center Edge; One-Pound Spherical Gelatin Launched at 188 m/s. (a) front view; (b) end view

(a)



(b)

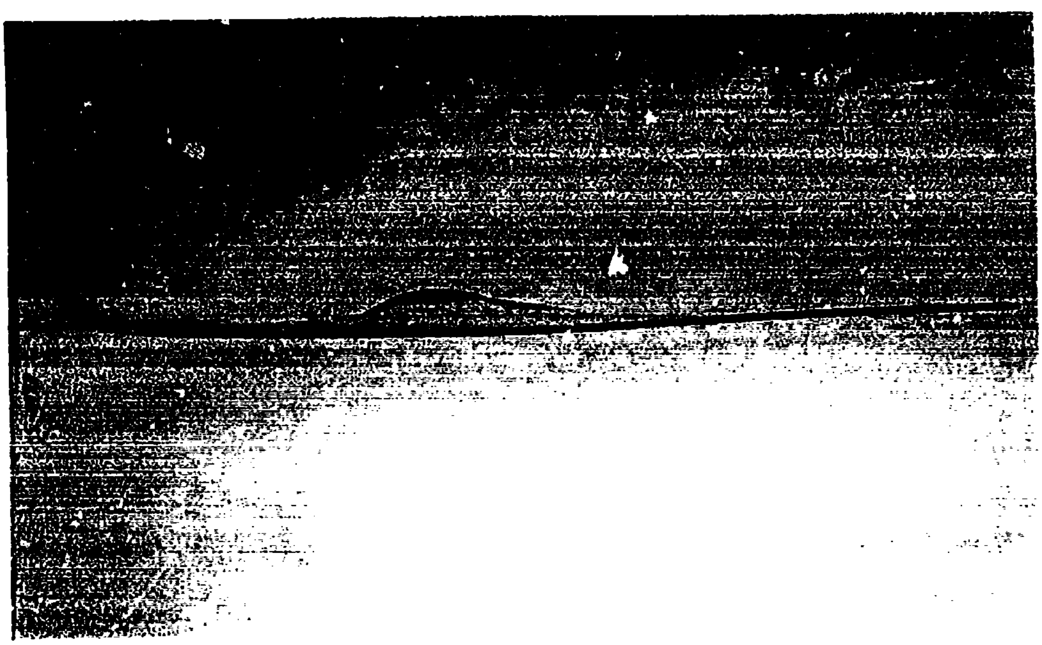


Figure A-3. Shot No. 5-0197; Panel Impacted at the Center Panel; One-Pound Spherical Gelatin Launched at 304 m/s. (a) front view; (b) end view

(a)

(b)

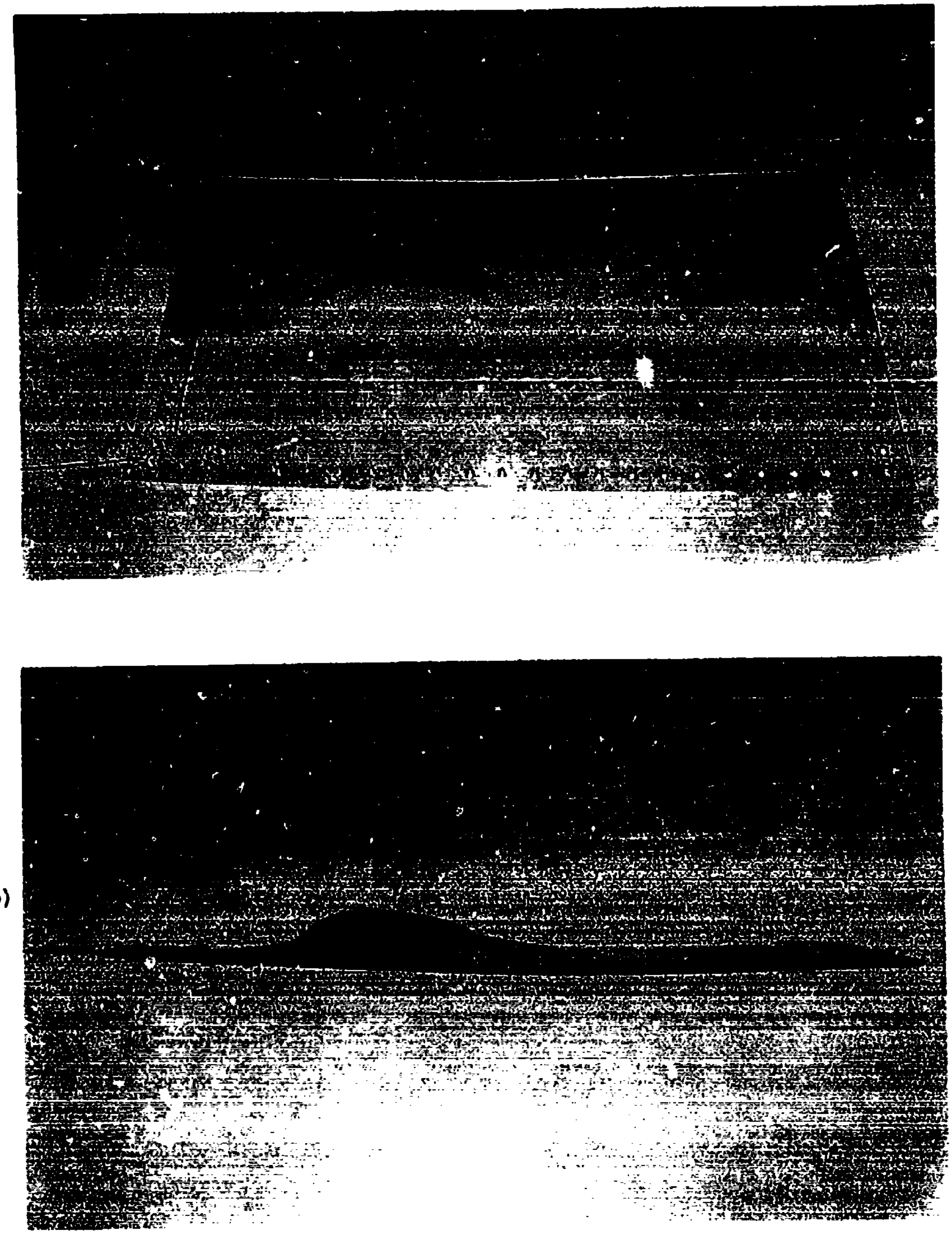


Figure A-4. Shot No. 5-0199; Panel Impacted at the Center Panel; One-Pound Spherical Gelatin Launched at 320 m/s. (a) front view; (b) end view

(a)

(b)

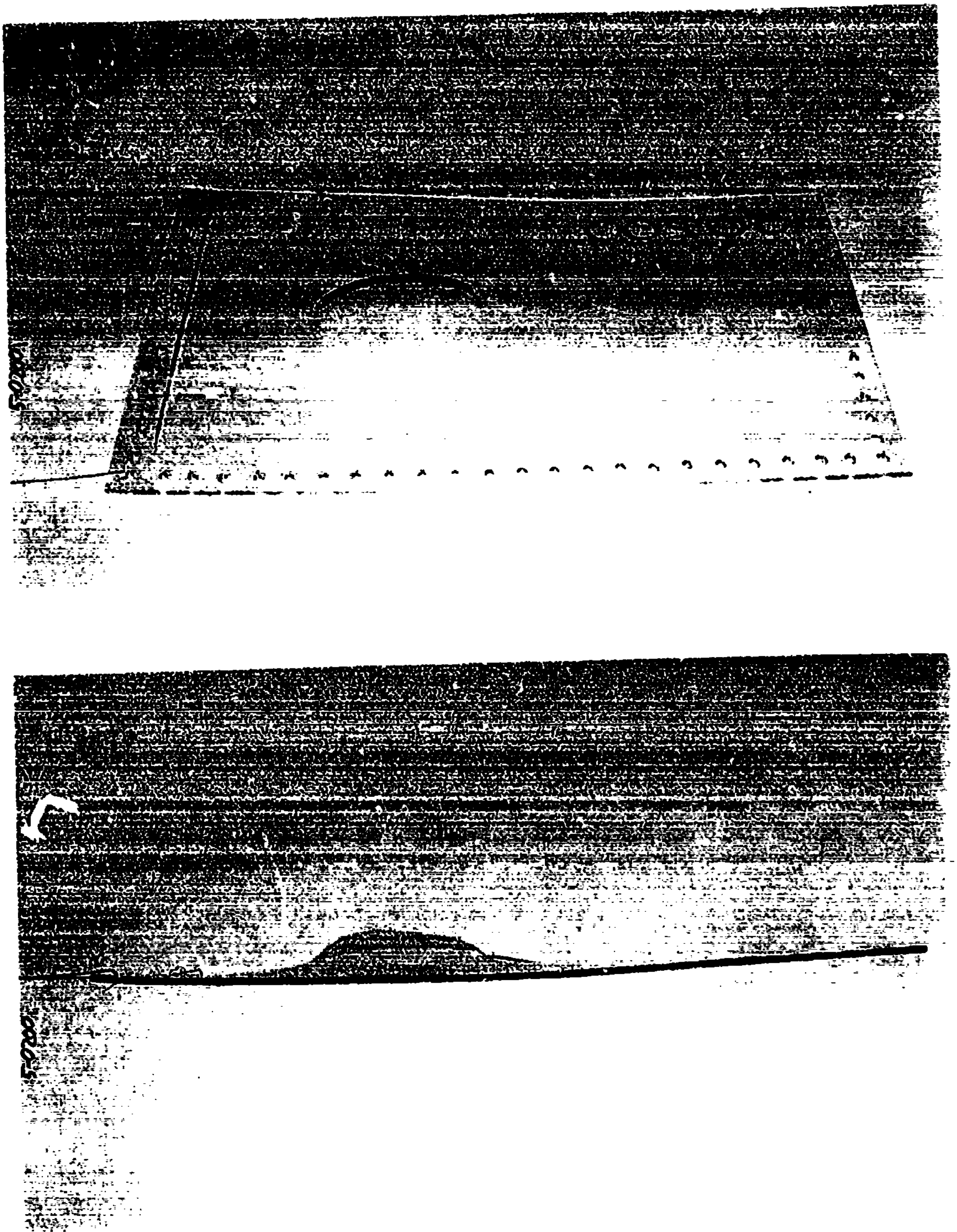
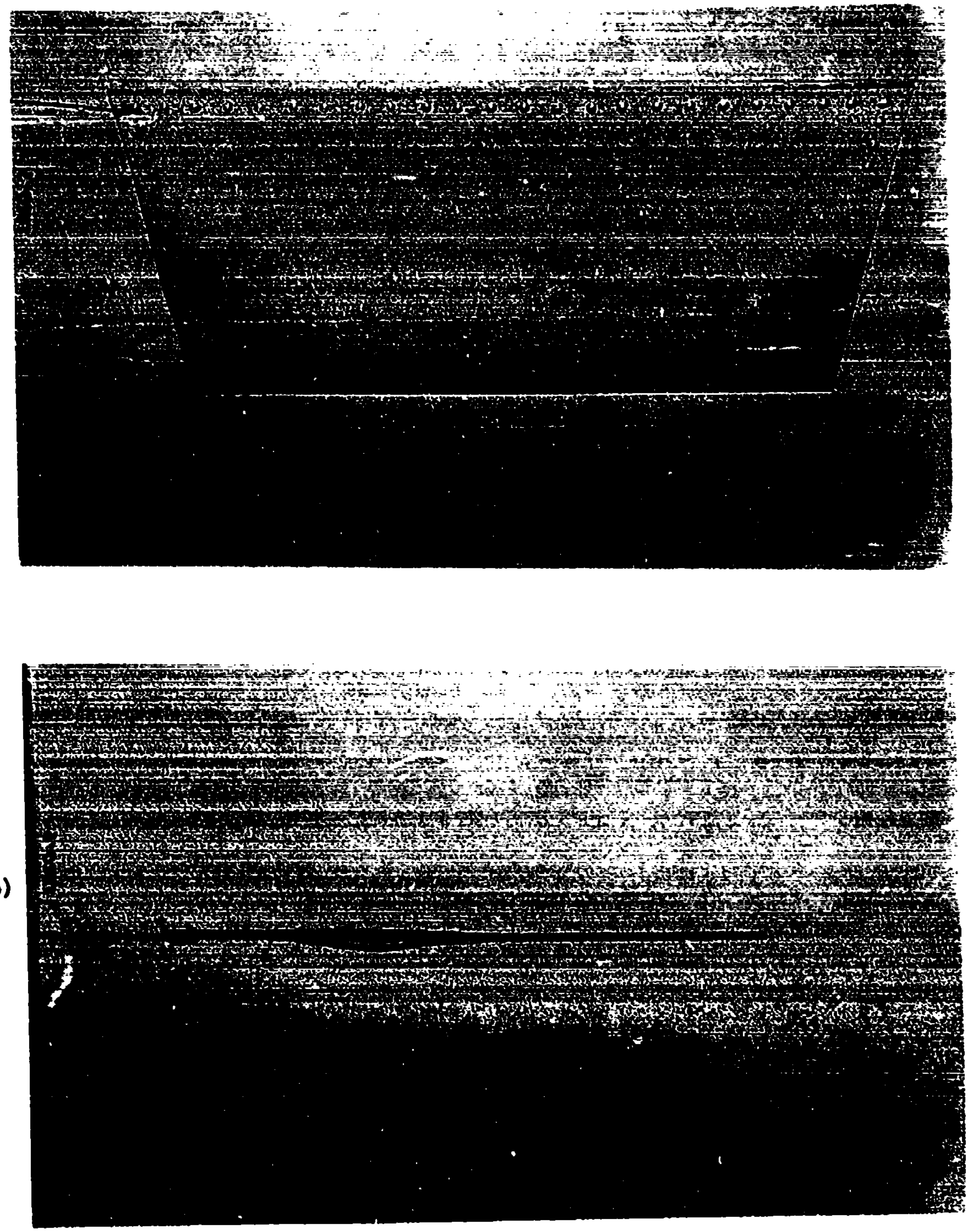


Figure A-5. Shot No. 5-0200; Panel Impacted at the Center Panel; One-Pound Spherical Gelatin Launched at >325 m/s. (a) front view; (b) end view

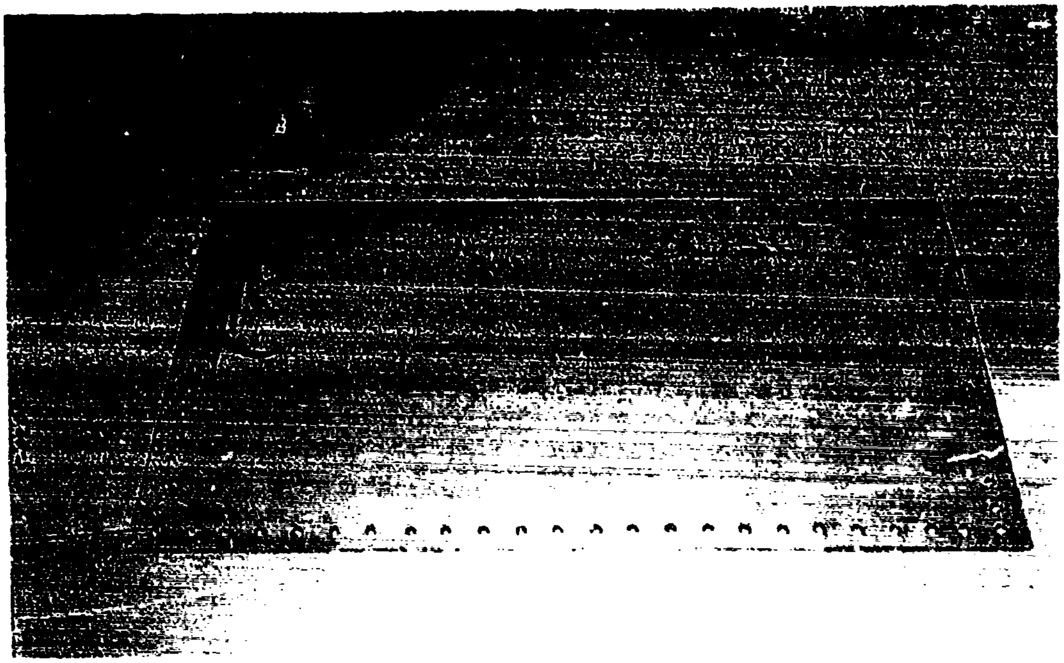


(a)

(b)

Figure A-6. Shot No. 5-0203; Panel Impacted at the Down-Stream Corner; One-Pound Spherical Gelatin Launched at 169 m/s. (a) front view; (b) end view

(a)



(b)

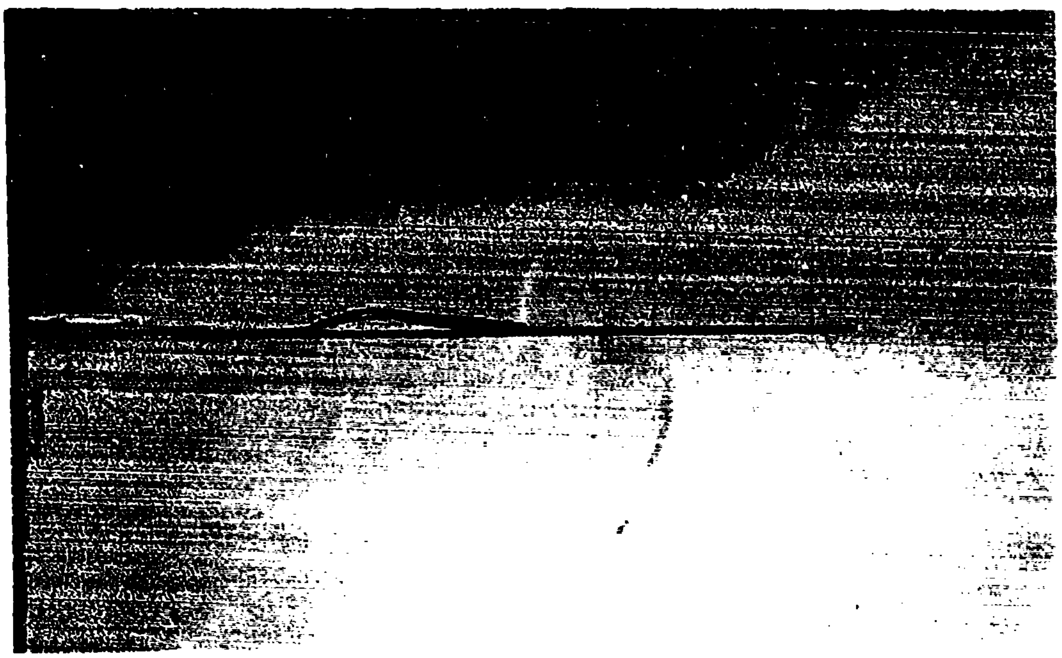
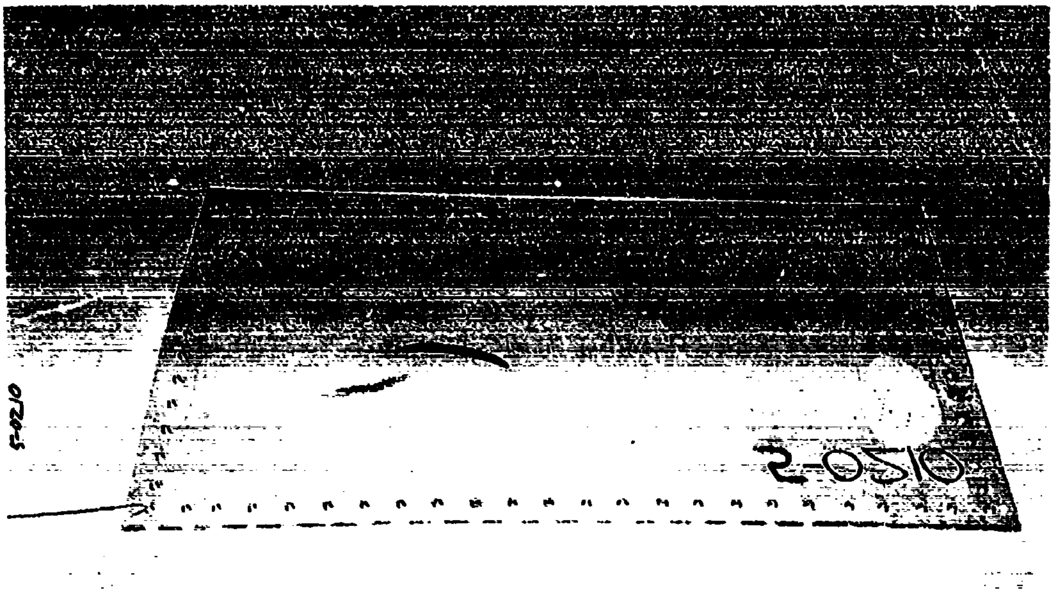


Figure A-7. Shot No. 5-0208; Panel Impacted at the Down-Stream Corner; One-Pound Spherical Gelatin Launched at 186 m/s. (a) front view; (b) end view

(a)



(b)

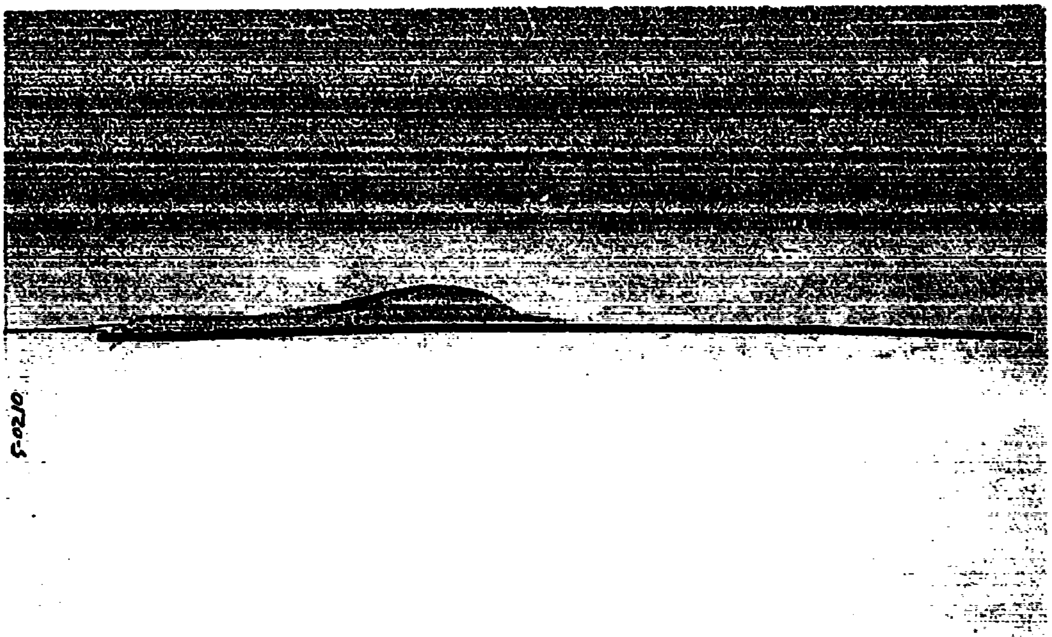
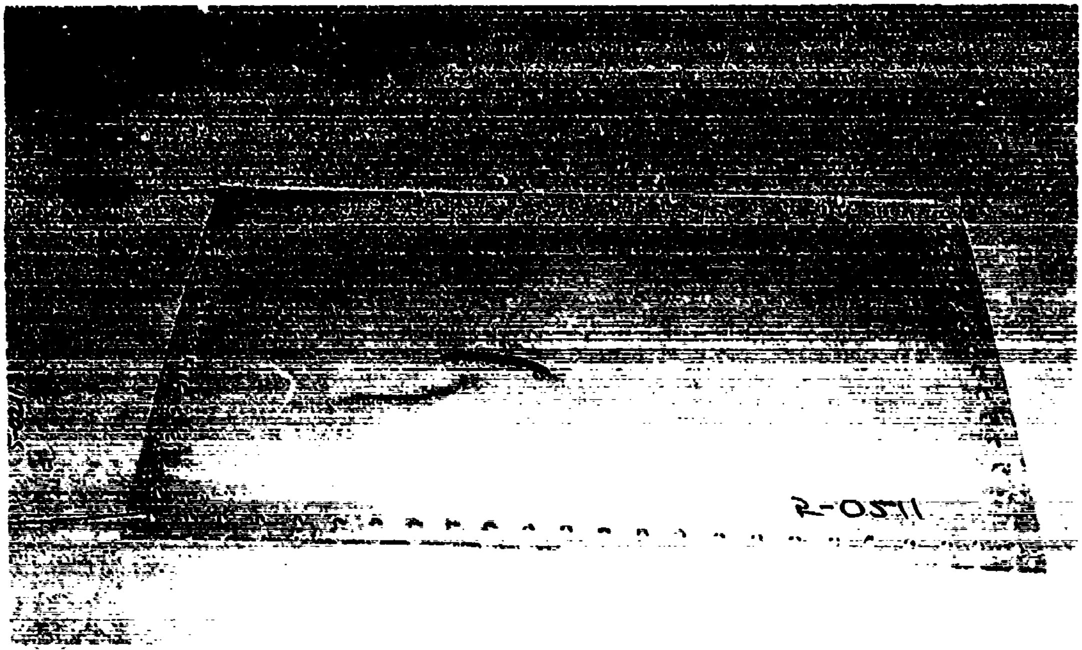


Figure A-8. Shot No. 5-0210; Panel Impacted at the Up-Stream Corner; One-Pound Spherical Gelatin Launched at 305 m/s. (a) front view; (b) end view

(a)



(b)

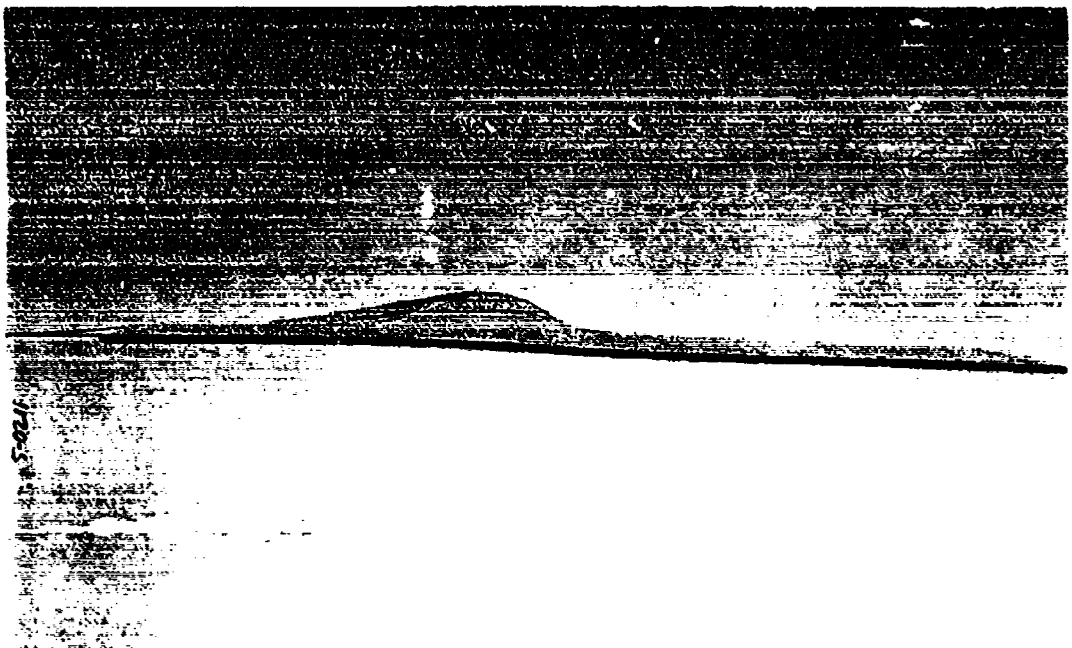
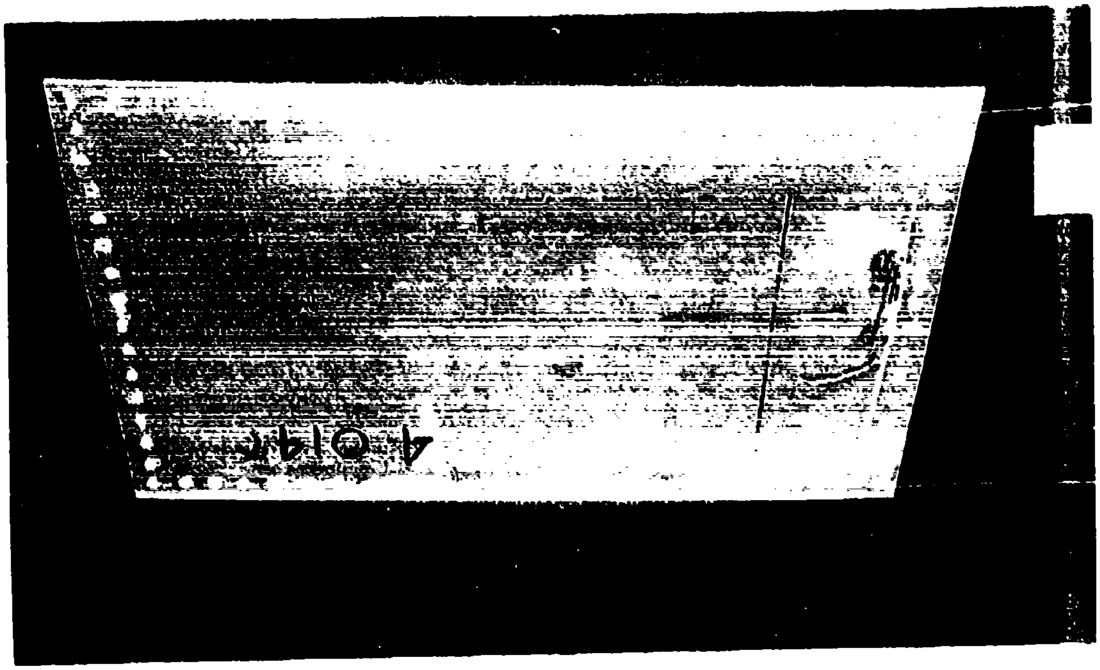


Figure A-9. Shot No. 5-0211; Panel Impacted at the Up-Stream Corner; One-Pound Spherical Gelatin Launched at 321 m/s. (a) front view; (b) end view

(a)



(b)

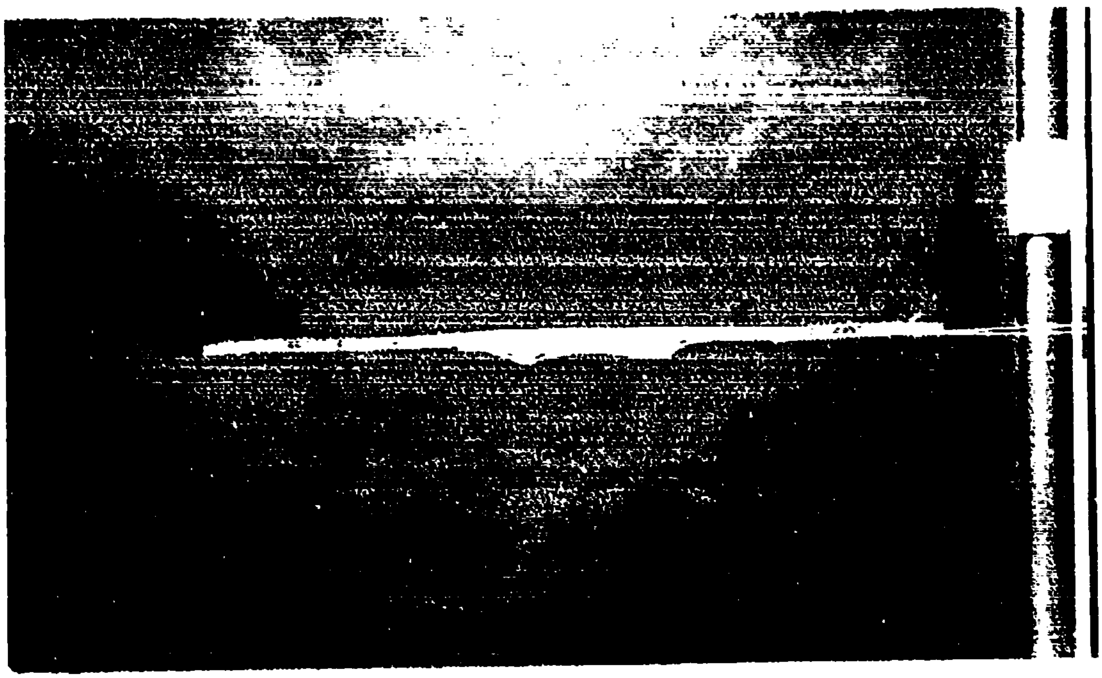


Figure A-10. Shot No. 4-0147; Panel Impacted at the Center Edge; One-Pound Pigeon Launched at 213 m/s. (a) front view; (b) end view

(a)

(b)

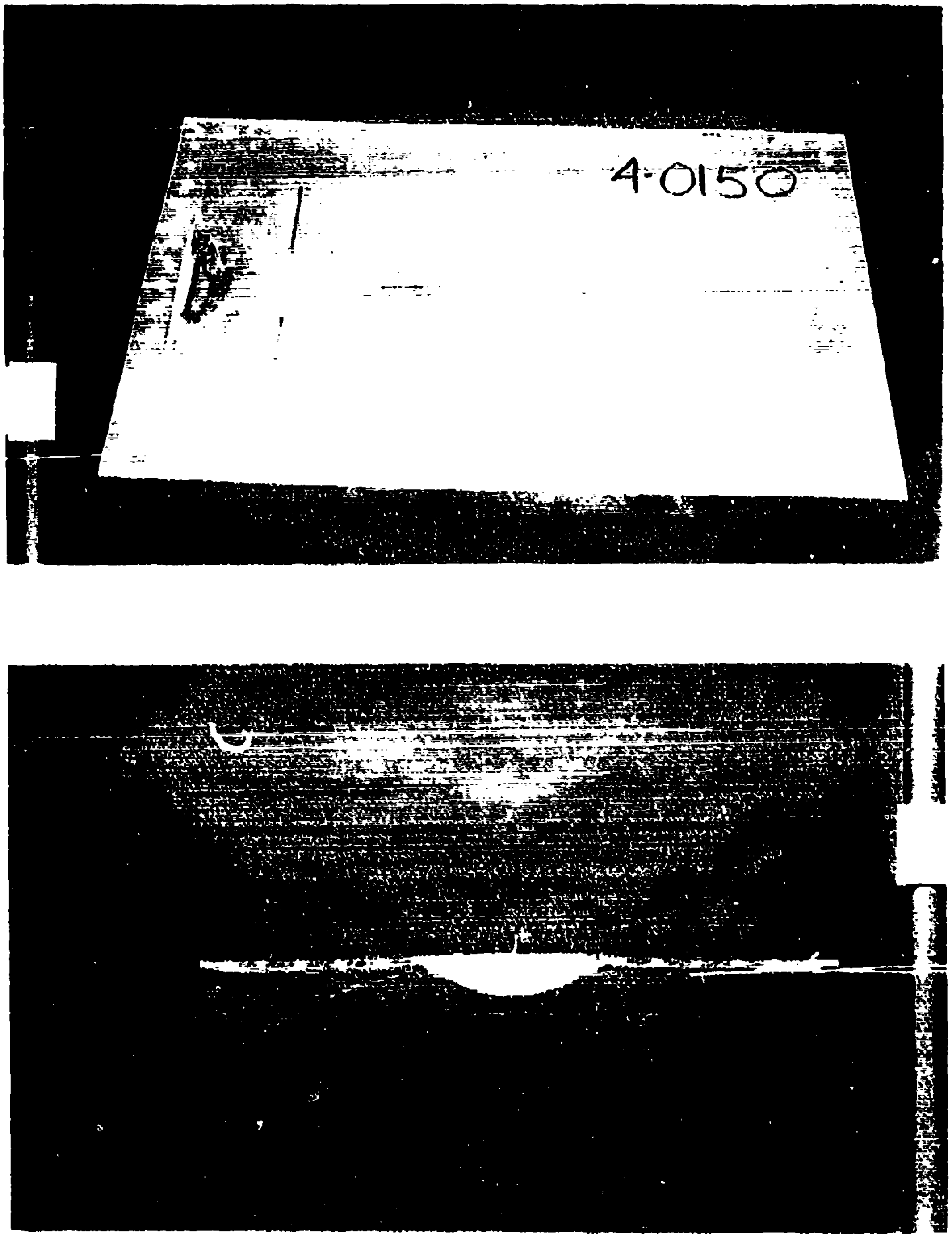
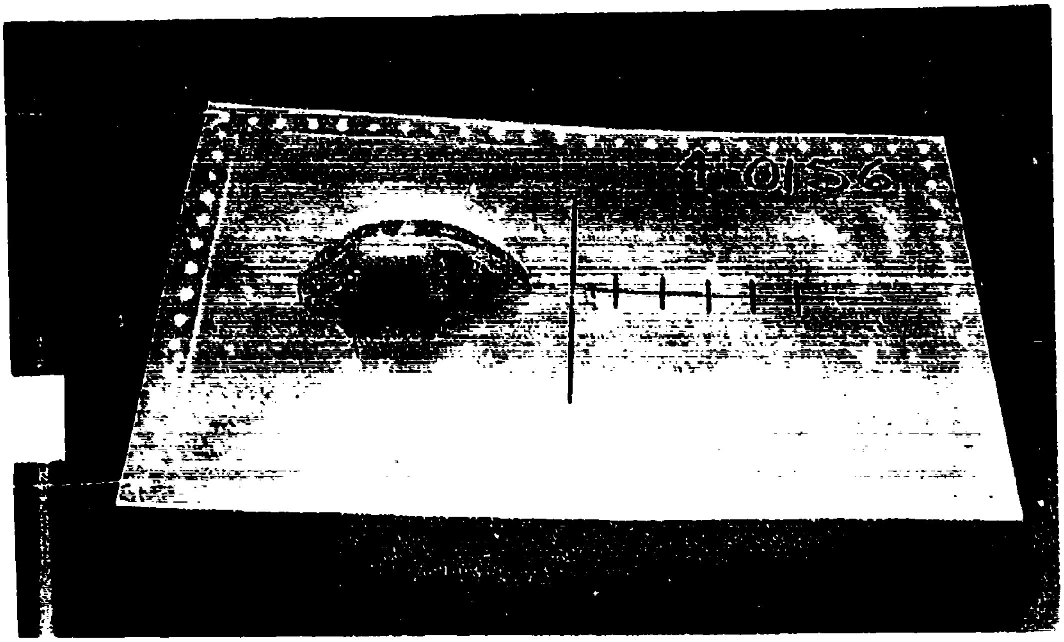


Figure A-11. Shot No. 4-0150; Panel Impacted at the Center Edge; One-Pound Pigeon Launched at 211 m/s. (a) front view; (b) end view

(a)



(b)

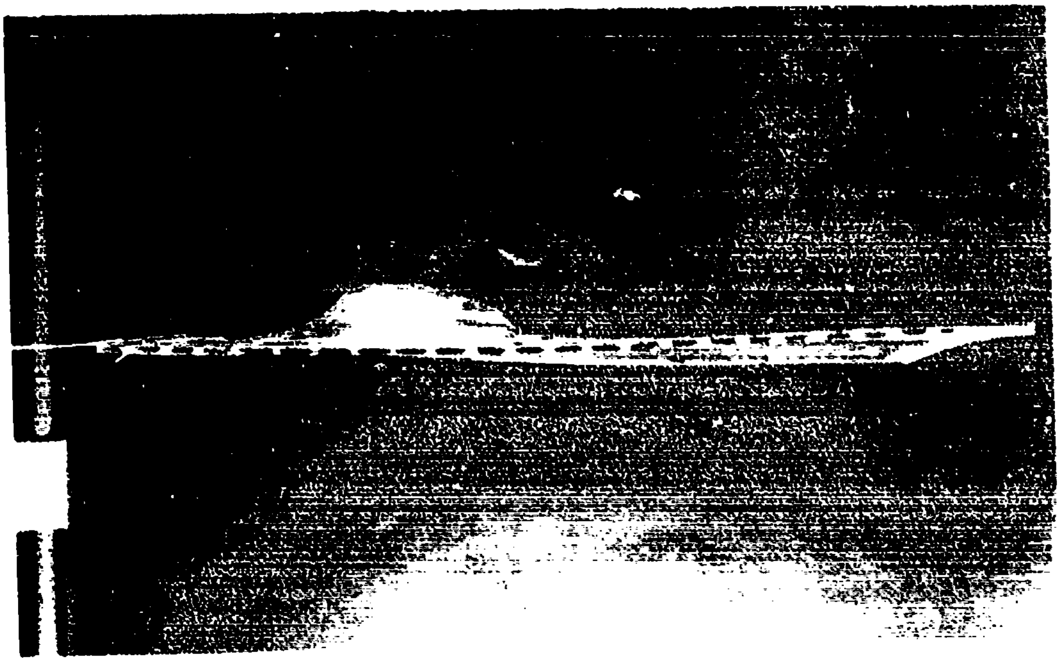


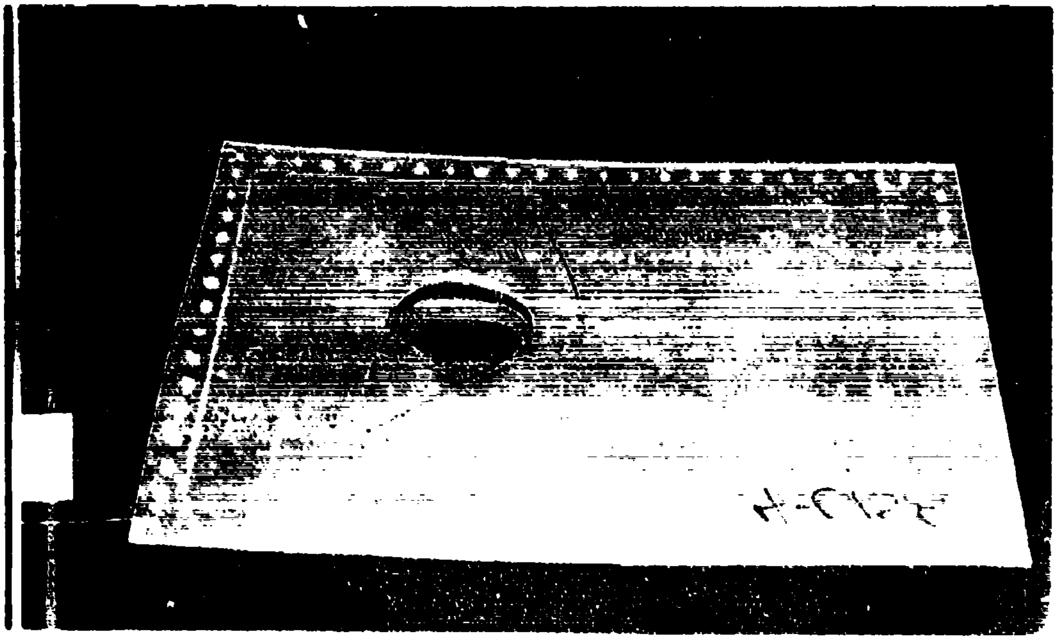
Figure A-12. Shot No. 4-0156; Panel Impacted at the Center Panel; One-Pound Pigeon Launched at 308 m/s. (a) front view; (b) end view

(a)

(b)

Figure A-13. Shot No. 4-0157; Panel Impacted at the Center Panel; One-Pound Pigeon Launched at 313 m/s. (a) front view; (b) end view

(a)



(b)

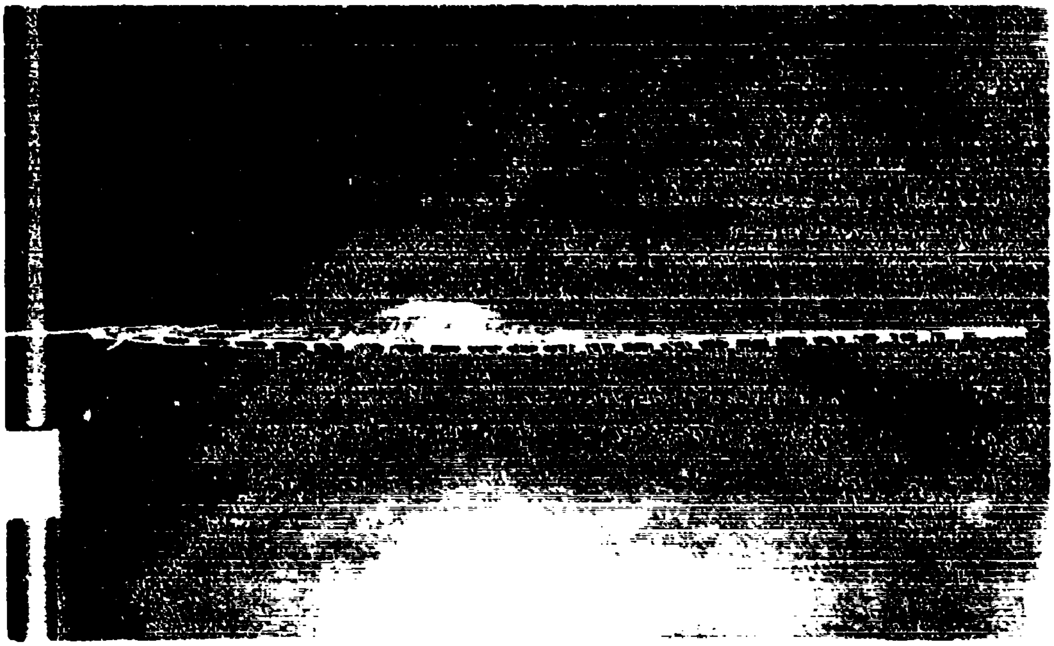
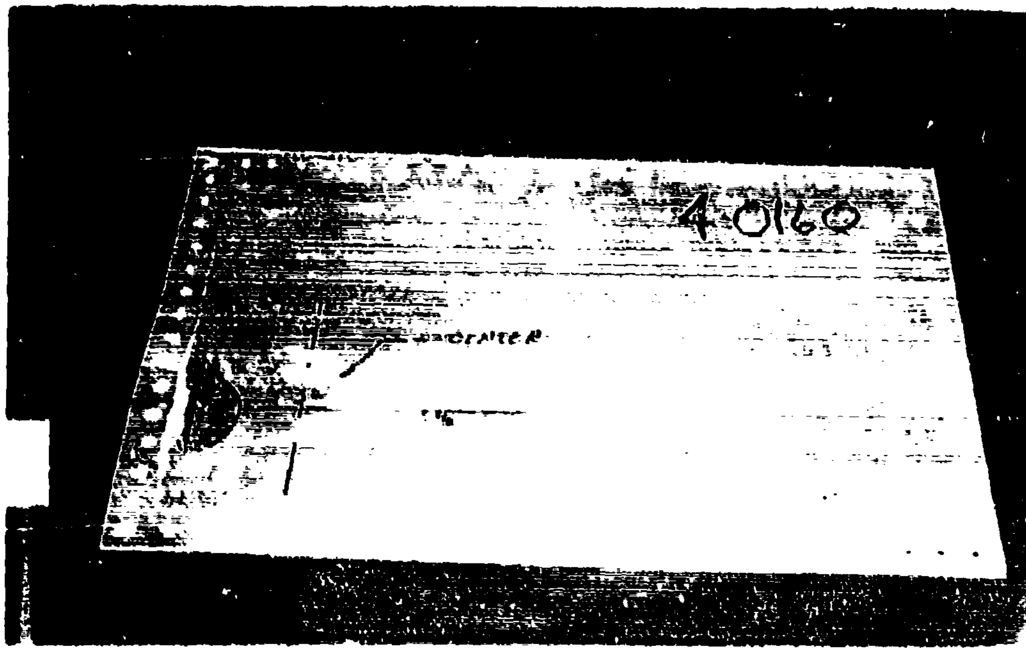


Figure A-14. Shot No. 4-0158; Panel Impacted at the Center Panel; One-Pound Pigeon Launched at 294 m/s. (a) front view; (b) end view

(a)



(b)

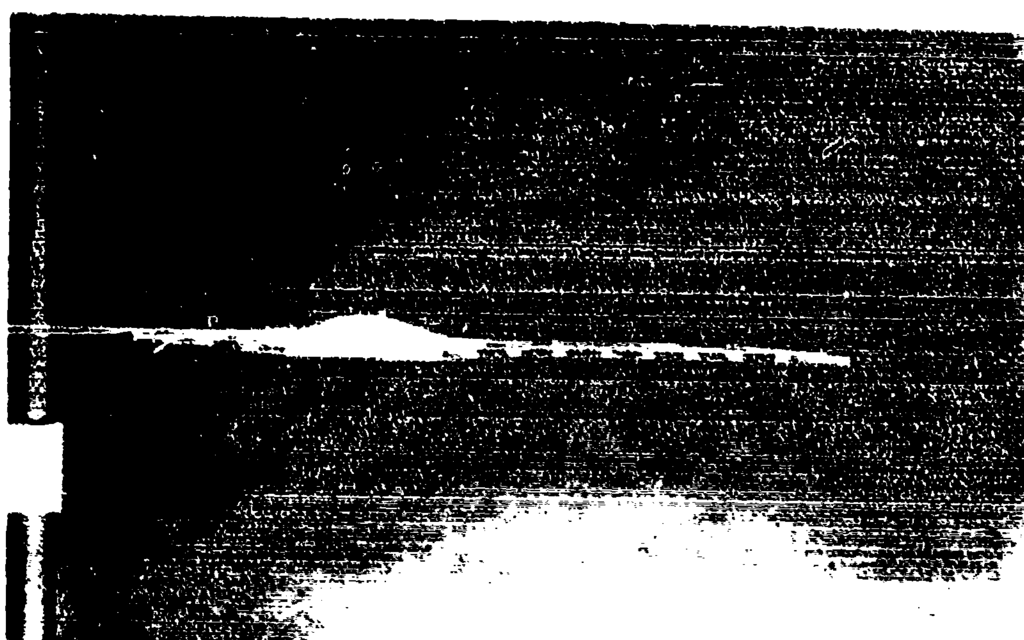
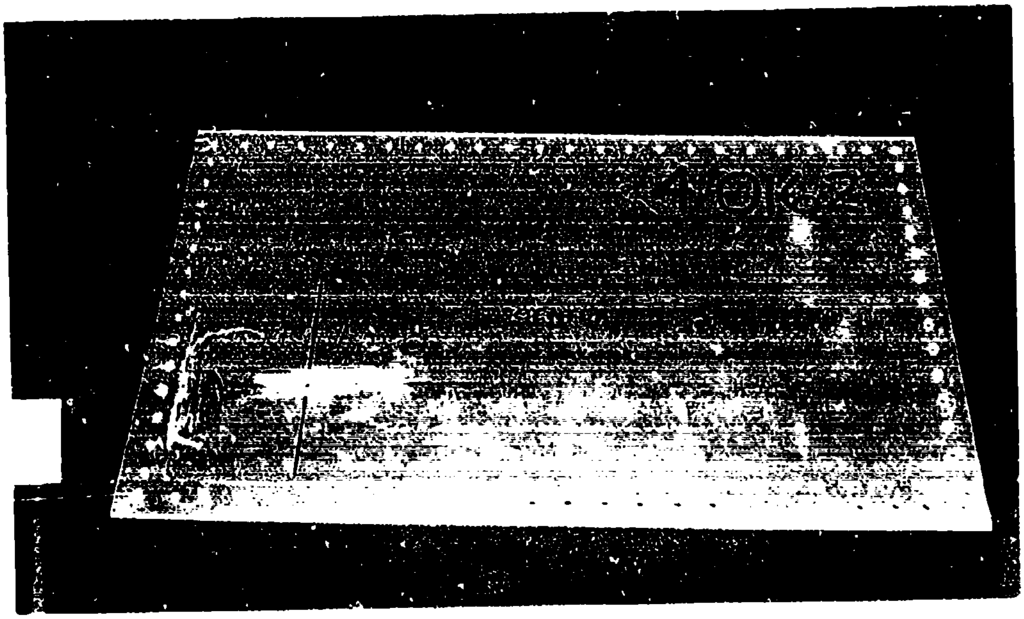


Figure A-15. Shot No. 4-0160; Panel Impacted at the Down-Stream Corner; One-Pound Pigeon Launched at 191 m/s.
(a) front view; (b) end view

(a)



(b)

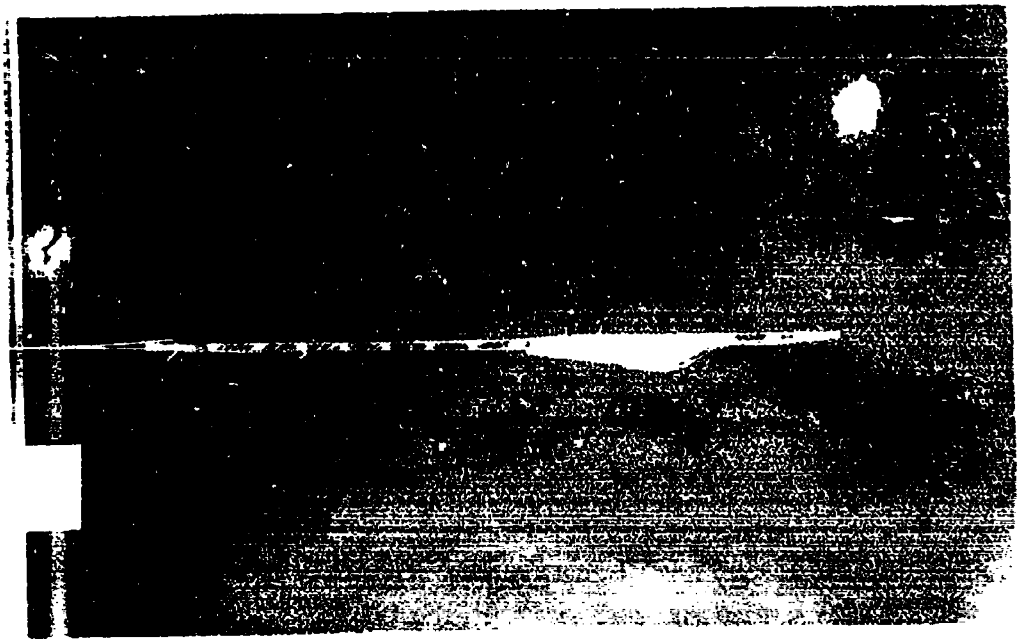
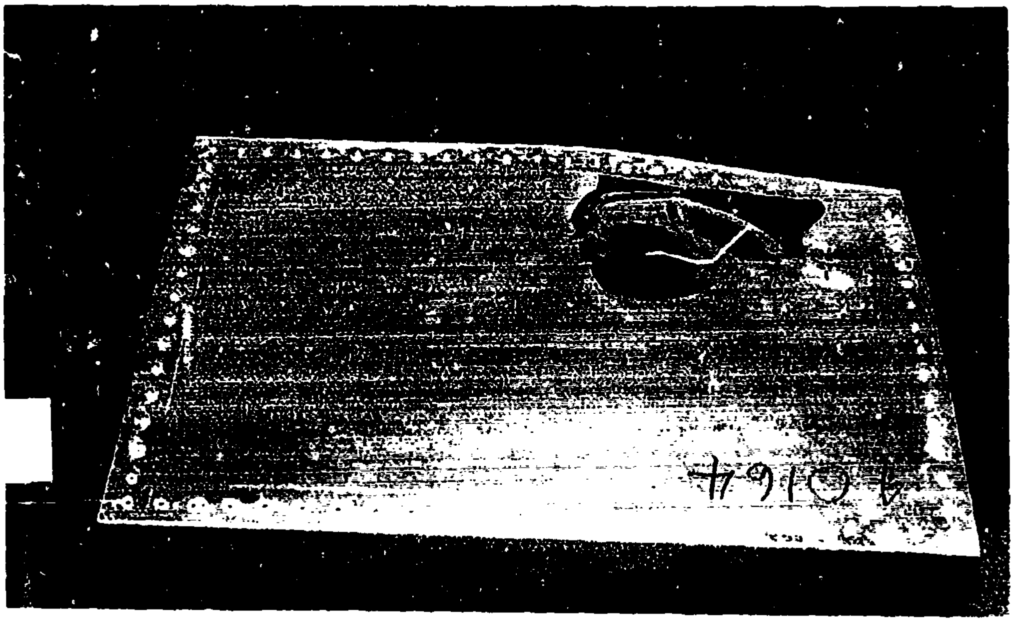


Figure A-16. Shot No. 4-0162; Panel Impacted at the Down-Stream Corner; One-Pound Pigeon Launched at 193 m/s. (a) front view; (b) end view

(a)



(b)

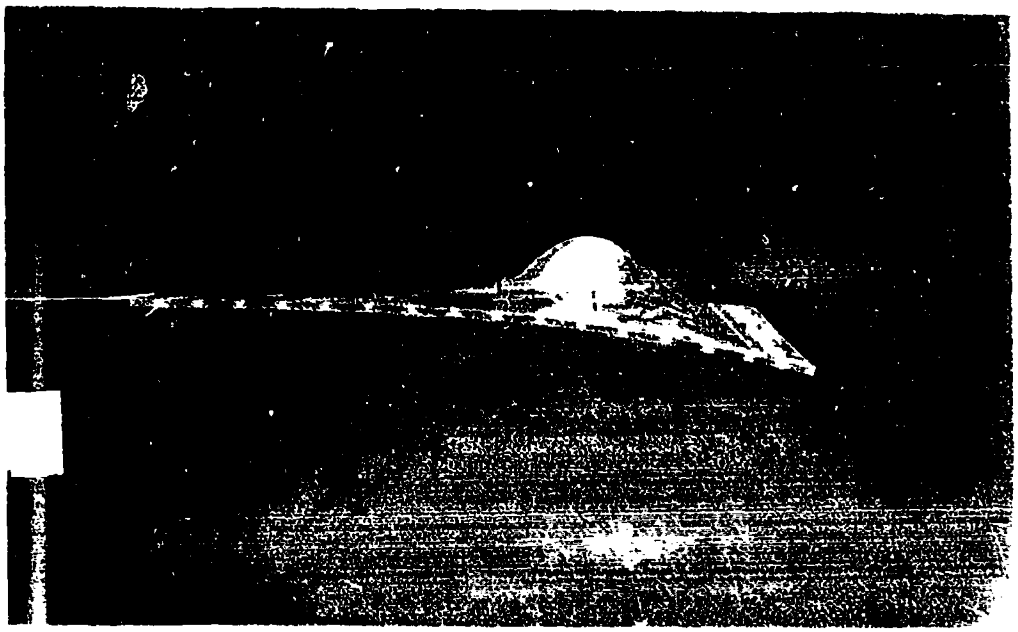
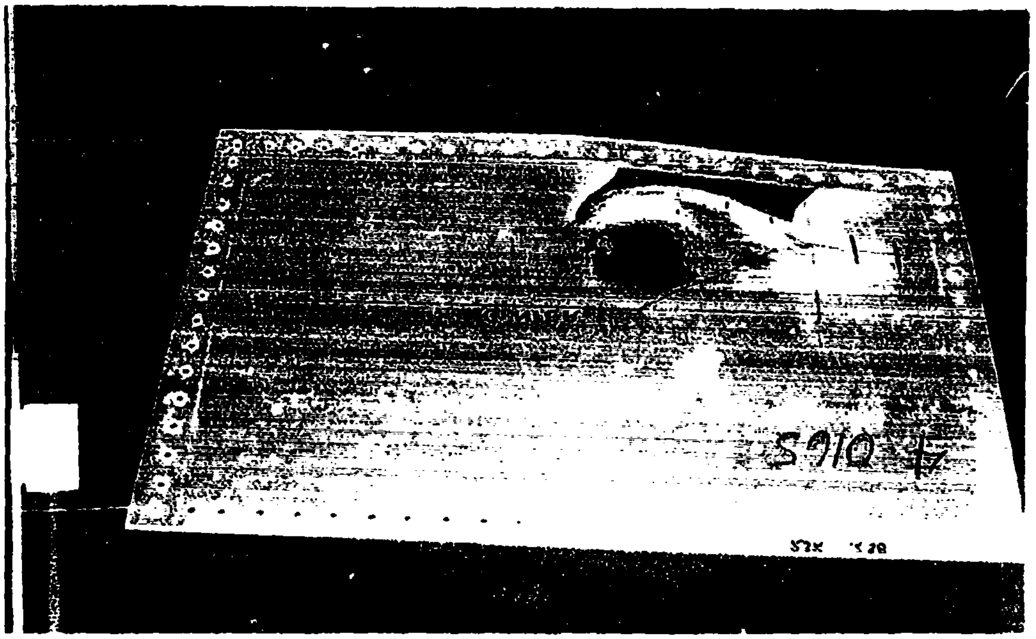


Figure A-17. Shot No. 4-0164; Panel Impacted at the Up-Stream Corner; One-Pound Pigeon Launched at 308 m/s. (a) front view; (b) end view

(a)



(b)

Figure A-18. Shot No. 4-0165; Panel Impacted at the Up-Stream Corner; One-Pound Pigeon Launched at 306 m/s. (a) front view; (b) end view

APPENDIX B
BIRD SUBSTITUTE SPECIFICATIONS

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BIRD SUBSTITUTE SPECIFICATIONS

From the work reported here and in References 1 by Wilbeck, 2 and 3 by Challita, and 4 and 5 by Barber, the following bird substitute specifications are proposed.

(1) The material of the bird substitute has to be gelatin with 10 percent porosity. It is recommended that an industrial grade gelatin (275 Bloom type A) be used; it is also recommended that phenolic microballoons (material type BJO-0930) be used to get the required porosity.

(2) The geometry of the bird substitute has to be a right circular cylinder with a length to diameter ratio approximately equal to two ($\pm$ 0.05).

(3) The bird substitute has to be homogeneous. High density gradients within the bird substitute are not acceptable. The recommended density is 0.96 g/cm^3; the maximum density variation within the bird substitute should not exceed 0.04.

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1. Wilbeck, J. S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.

2. Challita, A. and B. S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

3. Challita, A. and J. P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.

4. Barber, J. P., J. S. Wilbeck, and H. R. Taylor, "Bird Impact Forces and Pressures on Rigid and Compliant Targets," AFFDL-TR-77-60, May 1978.

5. Barber, J. P., H. R. Taylor, and J. S. Wilbeck, "Characterization of Bird Impacts on a Rigid Plate: Part I," AFFDL-TR-75-5, January 1975.

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1. Wilbeck, J.S., "Impact Behavior of Low Strength Projectiles," AFML-TR-77-134, July 1978.

2. Challita, A., and B.S. West, "Effects of Bird Orientation at Impact on Load Profile and Damage Level," AFWAL-TR-80-3009, June 1980.

3. Challita, A., and J.P. Barber, "The Scaling of Bird Impact Loads," AFFDL-TR-79-3042, June 1979.

4. Barber, J.P., J.S. Wilbeck, and H.R. Taylor, "Bird Impact Forces and Pressures on Rigid and Compliant Targets," AFFDL-TR-77-60, May 1978.

5. Barber, J.P., H.R. Taylor, J.S. Wilbeck, "Characterization of Bird Impacts on a Rigid Plate: Part I," AFFDL-TR-75-5, January 1975.

6. Bauer, D.P. and J.P. Barber, "Experimental Investigation of Impact Pressures Caused by Gelatin Simulated Birds and Ice," UDR-TR-78-114, November 1978.

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